EcoCost

Thesis

An
Ecological
Evaluation
System
for
Building
Materials

EcoCost

an ecological evaluation system for building materials

by

Langford

Stephen Sainsbury B.A.Env.Des. B.Arch.(Hons)

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Abstract

"EcoCost" is an ecologically-based evaluation system for building materials. The system assesses the reduction of biomass and biodiversity and the destruction of natural features, caused by obtaining, manufacturing, distributing and using materials.

The parameters of the EcoCost system include: pollutant output from industrial processes; land degradation caused by raw material collection; energy consumption and generation; pollution and land degradation due to transport; longevity of materials; resource scarcity; reusability and recyclability, engendered in creating a material and getting it to a site. The system synthesises data from a wide range of sources to give quantitative, consistent, repeatable impact evaluations to the various parameters.

In order to achieve a valid mathematical relationship between the disparate parameters of impact, a scalar range related to a constant base entity for each factor is proposed. Choosing a scalar range for ecological impact, between 0 (representing no impact) and 1, (representing the maximum impact) allows for the required mathematical operations to be made. There is only one single constant which all the various factors of ecological evaluation share and that is the planetary ecosphere, this is taken as the constant base entity. Each parameter is evaluated using these principal references.

The system then determines an overall comparative EcoCost with a linking ecological impact evaluation algorithm.

The EcoCost Algorithm

$$\textbf{EcoCost of Material} = \left(\frac{La + To + Ec + Td + \beta}{Longevity}\right) \times Re + ReE$$

Where

La	=	Σ Land Degradation Evaluations
To	=	Σ Toxic Output Impact Evaluations
Ec	=	Energy Consumption x Energy Production EcoCost
Td	=	Transport Distance x Transport EcoCost
β	=	Itinerant Impacts
Re	=	Recycled / Reused proportion factor
ReE	=	EcoCost of recycled / reused portion.
Longevity	=	$\frac{\text{Life of material}}{\text{Expected Building Life}}$

and

i) **Energy Production EcoCost = LaE + ToE + CeE**

Where

LaE* = Σ Land Degradation caused by energy production and fuel per MJ

ToE* = Σ Toxic Output Impact engendered in energy production per MJ

CeE = Capital EcoCost of Production Plant, amortised over life

that is ; $\dfrac{\Sigma \text{ Land Degradation} + \Sigma \text{ Toxic Output Impact}}{\text{Life of Plant (expressed in MJ Output)}}$

* Both the land area degradation and toxic cost should include the gaining of the raw material, processing and transport to the generating facility, for the fuel source.

ii **Transport EcoCost = Td x Σ (LaT + ToT + CeT + CeI)**

Where

Td = Transport distances for each transport type

LaT = Σ Land Degradation caused by fuel procurement and operation

ToT = Σ Toxic Output Impact of transporting motivator per tonne km

CeT = Capital EcoCost of Transporting motivator per tonne km

that is ; $\dfrac{\Sigma \text{ Land Degradation} + \Sigma \text{ Toxic Output Impact}}{\text{Life of Vehicle (expressed in tonne km)}}$

CeI = Capital Infrastructure EcoCost, amortised over life per tonne km

that is; $\dfrac{\Sigma \text{ Land Degradation} + \Sigma \text{ Toxic Output Impact}}{\text{Life of Infrastructure (expressed in tonne passes)}}$

iii) Itinerant Impacts, β, is determined from a series of sub-algorithms for each particular case

iv) The Recycled / Reused Factor, Re, is a simple percentage of the recycled / reused portion of the total consumed.

Re = 1 - % recycled / reused

$$Re = 1 - \frac{\text{Quantity of Recycled / Reused}}{\text{Total Quantity Used}}$$

v) The EcoCost of the recycled / reused fraction (ReE) is determined as a full EcoCost equation

$$ReE = \frac{LaR + ToR + EcR + TdR + \beta R}{Longevity} \times \textbf{Quantity of Recycled/Reused Material}$$

It could be assumed that Land degradation (LaR) would be negligible and Toxic impact (ToR) would be much less than the To of the new material, thus Energy (EcR) and Transport (TdR) become the important constituents for this parameter.

Preface

This work attempts to fill a major and widely recognised gap in the implementation of ecologically sustainable design practices. That is, of evaluating the alternative procedures and methods available for resource procurement. One of the principal problems with determining a suitable 'green' choice of actions is the absence of reliable evaluation systems based on actual environmental impact. This perceived void has resulted in a plethora of 'advice' based on hearsay, intuitive assumptions, subjective evaluations, (*Partridge 1993; Fox & Murrell, 1989*), and some preliminary biomedical research into associated effects of materials. (*Gijutsu & Kenkyujo, 1975; Richardson, 1986; Curwell 1991*). It is essential that systems of valuation became available which are based on the reality of the planetary ecosystem and its capacity to sustainably support consumption, rather than on subjective anthrocentric perceptions and concerns.

Such research as this is, nominally, the domain of the environmental scientist or economists, but the specific application of environmental research to any field requires an interface of knowledge from many fields. To a large extent, due to the breadth of information from diverse sources that must be pulled together, any realisable assessment of ecological impact must rest heavily on the previous work of analysts and evaluators in the environmental fields. It must be kept in mind that data is constantly being made redundant by the introduction and application of new understanding, new technologies and the constantly changing value systems of our culture. Due to the complex and diverse nature of the study of ecological impact evaluation it takes from and impinges upon all of humanities endeavours. The pioneering nature of specific study into the field must lead to protagonists from diverse disciplines making valid and worthwhile contributions to the debate.

The research required for the sort of evaluation system proposed herein is extremely arduous and complex and it is difficult to pin down relevant factors and information. This research is by no means complete or definitive. Enough, however, has been done and in sufficient depth to enable the setting up of a framework for a detailed analysis of humanity's impact on the environment which utilises available data.

A simplified advice system has been developed that can be practically applied to assess and compare the plethora of alternative materials, processes and strategies available to the concerned designer with current data and understandings. Extensive further research, data and development are required to develop more accurate and 'real' environmental costings.

In this case, dealing with the impacts of architecture, or at least building, it is essential that the traditionally non-mathematically inclined, technophobic profession of architecture is able to access the advice this system provides. It is necessary that it be presented in a format that is simple, straight forward and obvious in its structure. This particular thesis is a work based on the needs of architectural practice. The general application of the system developed herein at this stage must be subservient to this purpose. It should also be recognised that this system sits within an active scientific research context in this field, it takes the learning from analysing the limitations of contemporary environmental impact evaluation models to provide a further step in depth and accuracy of analysis. The EcoCost evaluation system is designed to be robust enough to employ a range of similar impact indexing systems simultaneously, the major provision being that the indexes used are biologically rather than anthrocentrically focussed.

It is intended that this work be used to allow architects to develop ecologically based costings and budgets. An EcoCost budget could be used to give an appreciation of how much resource and impact on the environment should be expended on the particular structure/place being dealt with, in terms of its social, cultural or contextual importance. The notion of EcoCost budgeting is a technique that can be applied by the designer to the work at hand in isolation from the 'economic necessities'. It will allow an informed series of choices to be made which would hopefully ensure that the designed object is the least consumptive and environmentally damaging possible.

It is vital in this era of environmental crisis that we become more aware of the wider effects of our actions on this planet, it is in this way that I see the EcoCost system being most aptly applied. This system is intended as a framework for developing advice for resource allocation and procurement decision making, with regard to the consequences of our acts, in ecological terms and with reference to the planet around us.

1.0 Introduction

1.1 Architecture, Ecology and Economics

We live in an era which is being forced into facing up to the dilemma of humanity's occupation of this planet. Through our short sighted attitude of striving for infinite growth within a finite and limited environment we are threatening the planet's, and hence our own, existence. Something must be done, but what ? Before we can answer this question we have to have a deeper understanding of the problem. What exactly is causing the planetary devastation that threatens us ? This thesis develops an information and advice system designed to give at least a preliminary usable answer to this question within the framework of available data and attitudes.

If we are serious about reducing the disastrous environmental impact of our species it is crucial that we develop and employ accurate, quantitative methods of assessing the full environmental cost of using particular products. Within the existing market pricing system, it is almost impossible to determine the environmental impacts associated with a particular product. It is too easy to use the product with the lowest market price and disregard the real costs involved. Systems are needed that have some penalty for using products which damage ecosystems and which encourage the use of environmentally benign products and methods.

Within the existing market pricing system, it is almost impossible to determine the environmental impacts associated with a particular product. If we are serious about reducing the disastrous environmental impact of our species it is crucial that we develop and employ accurate, quantitative methods of assessing the full environmental cost of using particular products. It is too easy to use the product with the lowest market price and disregard the real costs involved. Systems are needed that have some penalty for using products which damage ecosystems and which encourage the use of environmentally benign products and methods. To a certain extent, this is starting to occur by default as various ad-hoc anti pollution legislation around the world begins to take effect on industry. Recycling of car parts in Germany, zero emission requirements for 10% of vehicles sold in some states of the USA by 1996, recanting of pollution exemptions in Tasmania, all have some effect on the overall ecological predicament. It is simply not enough, changes must be made in the conceptual base assumptions of our social and economic systems.

The necessary changes will not happen within the current economic system, this system is one of the most intractable causes of environmental degradation,(*Pearce et al, 1989*). The manner in which we value products according to unreal criteria (in particular: capital, market interest rates and future discounting) leads inexorably to over-exploitation of the ecosystem for short term human gain, to the long term detriment of the planet. Investment capital is seen as a more valuable resource than clean air. In fact, there is no column on the balance sheet or profit/loss statement for clean air or for any other environmental capital degradation. There is no recognition of the limitations of the resource base or the concept of a sustainable economy. Current economics and market pricing systems are artificial human constructs which have no direct link with the ecosphere around us, particularly in regard to the detrimental impacts of our actions.

Our present economic system sets the value of any given item by the use of arcane monetary devices. These work by considering the man hours, overheads and desired profit margin that have gone into the extracting, refining and producing the object; in purely economic terms. The price is dependent almost entirely to the man hours involved in the process and vague concepts of supply and demand. Our economic system has, at present, no built-in loading which responds to the degradation of our world by the production of objects. The present system revolves entirely around humanity's assessment of its own worth in monetary and labour rate terms. The human time that goes into a product, covering costs and outgoings (which are simply someone else's time) is the only frame of reference for costing. We give things a price from a purely anthrocentric point of view.

Building consumes more resources than perhaps any other human activity, apart from the military industrial axis, (*Koistinen, 1980*). Buildings are the biggest single artifacts we make, and we produce a vast quantity of them. If, in the procurement of buildings, ways can be found to lessen the impact of consumptive practices then this can have a profound effect throughout our culture. It would not only engender a reduction in the detrimental impact directly but may also affect the way things are done in other areas.

Buildings have always been the most obvious and long lived of the statements of a culture's values, (*Vitruvius, hist; Corbusier, 1946*). Architecture is about the creation of artifacts that have a temporal as well as physical existence. Buildings are a legacy to the eras that follow, a statement of the principles of our culture extant at the time of construction. Architecture draws from all of mankind's activities for its *raison d'etre* and influences all the things that human beings do. It is in this sphere the EcoCost system was originally intended to make a contribution to the all pervasive argument of ecology versus exploitation. It has since developed into a broad ranging ecological evaluation system applicable to all ecological impacting activities. The focus of this thesis, however, remains the specification and procurement of building materials.

Architecture in our culture has often led the way in demonstrating the application of philosophical principles to the practical ways in which we do things. Our buildings are large scale symbols of our beliefs and desires for our future, as such they can be powerful education devices. Ecologically sensitive buildings are going to become the architectural hallmark of our culture (*Vale & Vale, 1991*). It is, seemingly, the way our society has decided to go and architecture should be in the vanguard, ecologically sensitive buildings will come to symbolise a transition to a more mature culture. They will demonstrate in solid reality the principles of a sustainable culture and the actual methods of achieving it.

Architecture has the potential to be one of the most rewarding and satisfying roles a person may take on in this culture. The unique blending of art and science that is required of its exponents also makes it one of the most challenging of civilisation's tasks. The challenge today is to make responsible buildings, (*Stulz & Mukerji, 1988; Union of Concerned Scientists, 1990; Buderim Report 1990; National Strategy for Ecologically Sustainable Development, 1992; RAIA, 1994*). The general low level of understanding of architects in so far as ecological issues are concerned has, in part, led to architecture being one of the most wasteful and damaging of humanity's activities, this must be redressed. Architects, designers and builders must become better, more educated and committed to higher goals. Buildings must be imbued with care and quality, they must meet real needs and must shake off the notion that they are simply ways to make money.

The current practice of using the procurement of buildings as a way of making money has become amongst the most damaging influences architecture has yet had to face, it directly affects the viability of the profession of architecture. Maximising profit (or nowadays simply 'financial loss, tax write-off') is in direct conflict with the making of fine, lasting architecture of an ecologically sensitive nature. Buildings consume prodigious quantities of resources and should as a consequence serve a distinct need and last for a long time. When buildings are frenetically flung together as quickly and cheaply as possible regardless of the ecological costs or aesthetic considerations or even an end user, limited to an 'economic life' of a decade or two and then pulled down to make way for another new structure, the high levels of consumption and impact involved must be amortised over a short period, dramatically raising the ecological cost. Something has to pay, somewhere.

'Something' is usually the environment, not just the ecological environment, but the social and economic environments. Very rarely is it those who caused the problem and reap the short term financial gain who pay for or are required to repair the damage they cause

To apply the principles of ecological sensitivity and sustainable cultural practices to the present way in which architecture is practised and 'controlled' requires a major paradigmatic shift. This can be attempted through either legislation or education or a combination of both (*United Nations Conference on the Environment and Development, 1992*). Legislation alone is not sufficient, it is too temporary and too prone to change. All the committed architects could work for a millennia only to have their work undone in a decade of wilful extravagance if the law were to be changed. Besides how do you legislate to make all building environmentally, socially and economically responsible ? (*Birkeland, 1993*) Only understanding can really solve the challenges created by the myriad problems confronting architecture. Genuine reform will only occur when the inescapable need for it is truly felt and understood by all, not because it is passed down as an order from some lofty elite. A vital part of achieving understanding of the detrimental effect of our actions is to have information and advice systems which can compare available alternatives and give them a comparative 'costing' in environmental terms. Once this missing link is provided the existing systems of resource allocation decision making can be viably used in this new context. Effective systems have evolved for 'cost - benefit optimisation' which can be directly applied to the process of product and system selection once a consistent reliable ecological costing system is developed.

An ecologically based costing system based on evaluations of the effects on the reality of the global ecosystem, lies in stark contrast to the present artificial, fabricated, manipulated economic system of valuation our culture has developed. A system based on empirically measurable realities (rather than confidence and expectation) would be extremely difficult to manipulate and would tend to a steady state, there could be no concept of unlimited growth in a sustainable ecological evaluation based economic system. The parameters of the system are limited by the ability of the planetary ecosystem and incident solar energy to sustainably support consumption. This does not mean that there could be no development. Improvement in living standards, health, education, or any of the myriad blessings of civilisation can still happen without growth. It simply means the concept that there are unlimited resources, land and waste sinking capacity available, for free, at the discretion of a detached bureaucracy, must be annulled.

Any evaluation system requirement must, however, relate to humanity, after all any usable system must be for humans to use. A sustainable system must make recognition directly of the value of integrity, satisfaction, beauty and strength, gentleness and appropriateness; as these are the baseline parameters upon which humans judge all around us. The resolution of this conflict lies in finding a common ground of evaluation. A beginning is to instil into our systems of valuation an evaluation of our effect on the natural world around us, as it is from that natural world that both our sensory aesthetic value system arises and the structure of our reality are based (*Fukuoka, 1975; Pirsig, 1985; Suzuki & Knutdsen, 1991*).

While recognising the worth of subjective valuation in the decision making processes of our culture they should be clearly recognised as such. Decision making should be based on a realistic evaluation of actual cost both objective and subjective versus subjective benefit. Cost is an issue of both objective and subjective valuations. Both of these are relevant in the decision making process. The current problem is that there is no clear differentiation between objective, nonanthrocentric impact analysis and subjective anthrocentric valuations of quality. The two parts are mixed and jumbled together creating great difficulty for rational (not rationalist) decision making. I use the term rational in a guarded way to describe a process of aware, cogent analysis and comparison of alternatives. The EcoCost system will provide a method of rationally assessing the biologically determined ecological impact of humanity's actions. This advice system may then be used in conjunction with other subjectively based cost benefit analysis to determine an integrated judgement.

1.2 The Purpose of EcoCost

The EcoCost thesis emerged as a response to a personally perceived lack in available design information. In order to practice architecture and building in a responsible way, a reliable indication of the environmental impact of available building alternatives is essential. The Ecocost system is designed to provide this missing advice which then becomes an integral part of the design process.

The thesis has as its principal aims:

- to investigate the concept of an ecological cost of material procurement;
- to analyse and critique current methods of evaluating the environmental impact of consumption of materials;
- to develop a biologically rather than anthrocentrically focused approach to the evaluation of ecological impact;
- to reduce the amount of unacknowledged subjective analysis in the evaluation of ecological impacts;
- to develop a robust framework which will facilitate the application of extant available information databases and impact indexes to ecological cost evaluation algorithms;
- to work through and compare example materials to verify the workability of the system and gain some indicative insights into the portents of the system's findings.

The thesis will commence with an overview and critique of the resource procurement environmental impact evaluation systems that have been developed over the previous thirty years or so. It will then develop the EcoCost ecological evaluation system by looking at each of the parameters in turn and then the evaluation system as a whole. Two comparative examples will be worked through and some findings detailed that have been deduced from the application of the system.

2.0 State of the Art.

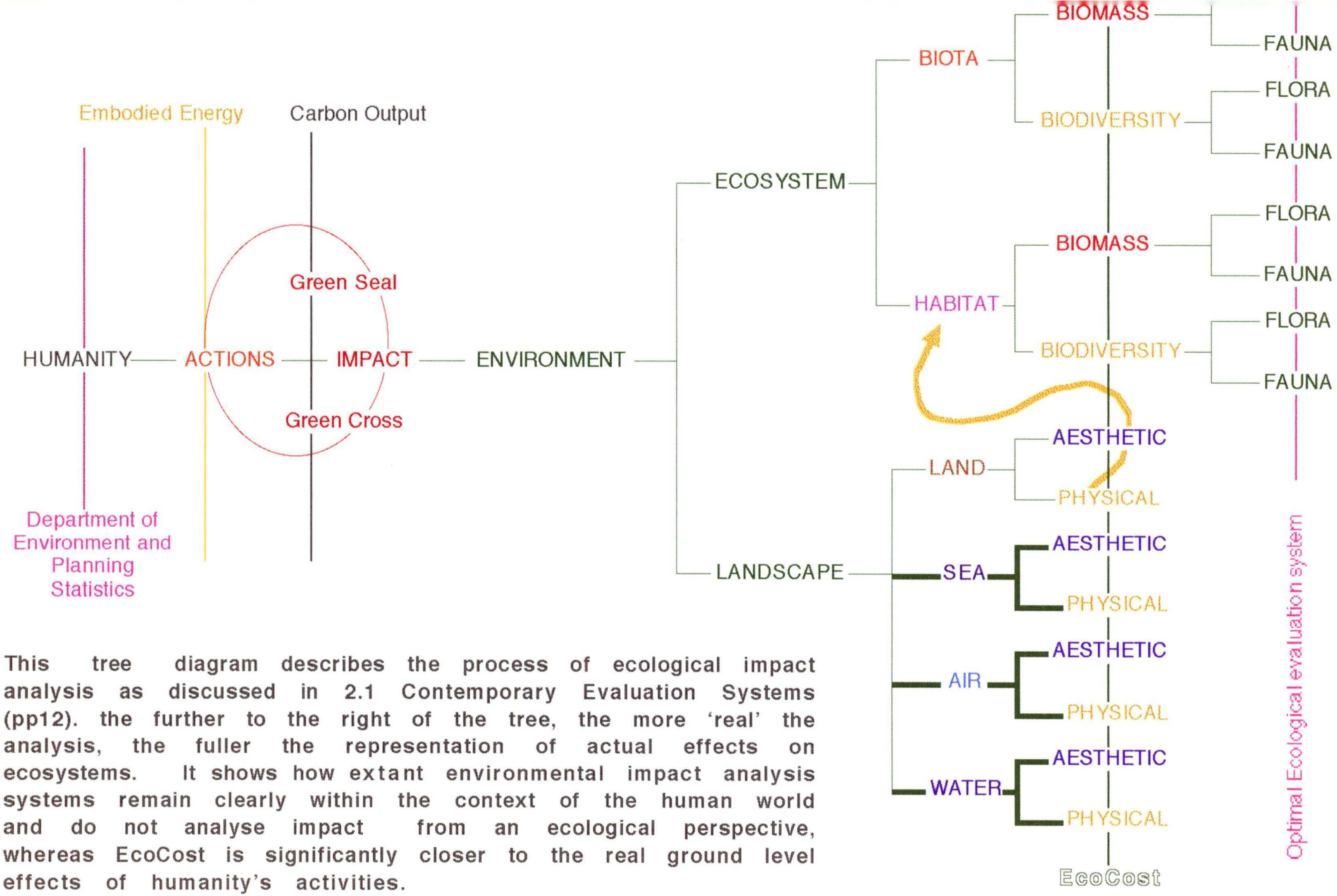
2.1 Contemporary Evaluation Systems

Many recent writers in the environmental arena have expressed the need for a broad-ranging ecological evaluation system that would give a realistic idea of the environmental impact of using certain materials or products.*(Fox & Murrell, 1989; Vale & Vale, 1991; National E.S.D. Strategy, 1992; Oppenheim, 1992).* Numerous systems of ecological evaluation have indeed been proposed and developed over the last few decades.

Early investigations into the environmental damage caused by human activity tended to look at individual elements causing impact. In 1971, the United States Council on Environmental Quality (U.S.C.E.Q.) sponsored the Mitre Corporation to develop a set of environmental indices. These developed into a limited assessment of air quality relating to the perceived major pollutants of the time. This involved a fractional analysis of individual pollutant concentrations compared to national health and safety standards, together with an additive approach to linking the effects of the pollutants, (*Bisselle, Lubore & Pikul, 1972*). This gave a partial 'state of the environment index', which the U.S. C.E.Q. applied to analysis and decision-making processes. While a useful starting point, this system is very limited in its scope and does not address numerous wider issues of environmental impact. Land degradation through raw material procurement, transport impact, energy generation impact, limitation of resources, and wider biota effects were not considered.

The Batelle Memorial Institute, in Ohio, U.S.A., (*Reiquam, 1972*) developed a system of assessing environmental stress contributed to the ecosystem by toxic chemicals emitted by industrial processes with respect to: the range of effect from local to global; it's persistence from hours to millennia, and; the level of complexity of its actions. Although this system was developed in order to give a weighting to each toxin according to its overall effect or stress on the environment, the system still assigned values to impact in an arbitrary, subjective way.

The first significant, widely used evaluation system employed energy consumption as an indicator of environmental impact. The system was developed and refined in the early nineteen



This tree diagram describes the process of ecological impact analysis as discussed in 2.1 Contemporary Evaluation Systems (pp12). the further to the right of the tree, the more 'real' the analysis, the fuller the representation of actual effects on ecosystems. It shows how extant environmental impact analysis systems remain clearly within the context of the human world and do not analyse impact from an ecological perspective, whereas EcoCost is significantly closer to the real ground level effects of humanity's activities.

seventies. It was considered the only form of evaluation possible given the limited information bases available at the time. It was an evaluation process that could be clearly defined by rigorous guidelines within the rules of objective scientific research (*Popper, 1968; Bousted & Hancock, 1974*). Improvements gained through energy audits had an immediate economic correlation with the price of energy and could by carried out by 'trained objective professionals'. This process has developed into the contemporary concept of 'embodied energy' (which is a misnomer, as practically all the energy is dissipated, not embodied). This method has no relationship to actual ecological or environmental impact, as it takes no account of how the energy is generated, or dispersed, or the numerous other factors causing environmental damage.

The emerging awareness of the 'greenhouse effect' led to the use of the correlation between energy consumption and carbon output as an environmental evaluation (*Wilkenfield & Co., 1990; OECD, International Energy Agency, 1991*). This system measures the amount of carbon-based compounds released by the generation of the energy required by the manufacturing (and sometimes the distribution) process. While carbon output measurements highlight a particular environmental problem source, the concept is still too narrow. Carbon comes in many forms, diamonds, graphite, petrol and human skin are all carbon based. It can be living, dead or inert and its various forms behave in vastly different ways, especially with regard to the environment. The carbon output system has also been adapted to calculate the quantities of carbon stored in organic products used in the material. This supposedly represents carbon that is being tied up rather than released into the atmosphere. The whole concept deals with only one element out of the dozen or so active in environmental impact (and then only a few of its manifestations), it is too narrow and unreliable a base for an ecological evaluation system.

The U.S. Environmental Protection Agency (U.S. E.P.A.) has developed a 'Green Seal' program which uses skilled analysts and environmental auditors to assess a process and rate it according to a complex series of criteria: objective, subjective, ecologically-based, environmentally-based and socio-politically based. The idea is to issue Green Seals of approval to products produced by organisations conforming to established standards of environmental behaviour. These standards are set suitably low (in accordance with 'best achievable technology') to allow a reasonable number of industries to obtain a commendation to ensure support from industrial lobby groups. These evaluations are based on a limited series of criteria, a number of which require subjective assessments. They take no account of post production transportation, energy, or other issues. They do not attempt a comparative appropriateness rating for materials and hence are not of use in making finer decisions between alternatives. (*Progressive Architecture (March '93)*).

There are a number of other governmental and private certification systems around the world operating along the same lines as the Green Seal system. Ecologos in Canada and the European Economic Community (using skilled evaluators and a series of established criteria) fall into this category, (*Progressive Architecture (March '93)*).

Scientific Certification Systems (formerly Green Cross) in the U.S.A. have been developing their environmental evaluation system with its associated databases and skilled evaluators for more than a decade. They have started to produce Environmental Report Cards which give a series of graphically-presented ratings to a product, based on a range of environmental factors. Most of their databases appear to be derived from the U.S. E.P.A. industrial output source data and energy audit information. The system uses only a limited range of environmental impact factors, mostly chemical pollutants, energy costs and resources used. While it is an advance on other systems, the Environmental Report Card makes no effort to integrate its limited range of factors into a combined overall rating. It ignores transport factors and land degradation impacts. (*Scientific Certification Systems, 1992*).

Partridge Partners, an Australian firm of environmental engineers, have recently developed an environmentally-based evaluation system for building materials which looks at a wide range of environmental impacts resulting from procuring building materials, (*Partridge, 1993*). The system, called the Ecological Assessment Factor, uses a weighted points system for a number of factors to give a simple numerical value to a product. Comparisons may then be made between materials using these numbers. The system relies entirely on qualitative, subjective assessments for determining the initial points ratings but does give a form of comparative evaluation. Verifiably and subjectivity of assessments is a weak area.

While each of these methods is a step along the way to a complete environmental evaluation system, there is much room for improvement, especially in terms of assessing the actual on site impact on ecosystems and bringing together of the wide range of influencing factors. Due to the vast range of sites and data, sufficient resources are not available for actual field assessments to cover all the aspects of ecosystem impact to a fine enough degree for each individual product and process. While complex mathematical simulations of ecosystems and the effects of impacting factors have been a field of active research and development for decades, their proponents would admit that they are far from achieving a practical and comprehensive ecosystem model (*Reiquam, 1972; May, 1973; Marsh, 1978; Rau & Wooten, 1980; Roberts, 1985; Margules & Austin, 1991*). Even given current and forseeable limitations, this field will eventually provide the necessary base information for definitive ecological impact analysis and evaluation systems.

2.2 Commercial Environmental Evaluation Systems

A dangerous precedent would appear to be developing in the ecological evaluation field. A number of organisations have emerged (mostly on the Northern American continent) which have developed what they consider to be confidential, commercially viable environmental evaluation systems, (*U.S. Environmental Protection Agency, 1991; Scientific Certification Systems, 1992*). These organisations contract out, at significant rates, to specific manufacturers to give a rating or series of ratings based on environmental parameters. These ratings are used by the manufacturers to enhance marketing prospects. The potential for the misuse of such commercial systems through relaxation of rigour or the use of monetary bargaining strength in this economically driven world is immediately apparent.

It is critical to the worth of any evaluation system that it's objectives and short comings are stated obviously and clearly. The evaluation system must clearly state its parameters and exactly what it is evaluating. A commercial operation is unlikely to advertise it's flaws and is more likely to preach it's supremacy or positive attributes. The parameters used by these rating organisations fall well short of a thorough ecological evaluation but are touted as scientific corroborations of environmental claims. In many cases the subjective opinions of (indisputably) skilled analysts are used in certification systems claiming objectivity. There is a great deal of 'pulling of the scientific wool over the eyes' of the non-technical, consuming public.

Openness, diversification and formal, generally accepted standards are the best armaments against these problems. If a number of widely accepted evaluation systems are developed by concerned researchers combined with the opening up of 'confidential' government pollution data for broad public use then the potential for malpractice or disinformation is dramatically reduced. Anyone familiar with a given system would have access to the necessary data sets to check the assessment themselves. The commercial ventures would come from working through a known and agreed system, saving labour for the specifier as opposed to selling a competitive product.

The strong tendency of the academic community towards critical review, can cause those not fully confident of the validity of their system to take cover under the blanket of commercial confidentiality. The current state of affairs in environmental impact assessment, with confidentiality and secrecy everywhere, strongly smacks of psychosis, verging on paranoia. What are 'They' (or even, 'We') afraid of? What do our governments, the major industrial corporations and these rating organisations want to keep secret from their competitors and the general public alike?

The same reasoning and questions apply to industrial pollution data. One wonders why it is in the public interest to have the reports of pollution and degradation analysis withheld from the general public. Are we too immature and unreliable to be allowed to know just how badly we are being poisoned by these organisations; or more accurately, by our own desires for rampant consumption? Or more likely are we so bound up in the pursuit of the concept of growth that we will brook no opposition to it and thus deny any possible use of any information which may be perceived as detrimental to unlimited growth?

These questions require answers which currently have no conscious existence, there seems to be no cognizant entity that could answer them. A considerable portion of the malaise lies in this lack of sentient direction for our culture. We have allowed a sort of accidental, ephemeral, unconscious entity to develop, constituted by our faceless bureaucracies, limited liability corporations and transient power chasing governments. Some answers may lie in the recognition of the existence of this arbitrary presence that forms so much of our cultures overt attitudinal responses. The transforming of this entity into a sentient, sensitive, environmentally and humanistically aware organism is critical to the sustainability of our culture.

Regardless of the need for paradigmatic shifts, it is critical that reliable verifiable evaluation systems of our impact on the global ecosystem be developed. These systems, using widely agreed parameters and methods, must be brought into the public domain as a matter of urgency in order to underpin any push for change on the firm foundations of the reality of the planetary ecosystem.

2.3 Information Systems for Decision Making

Ecological evaluations of various sorts are becoming widely used in decision making in such areas as environmental impact statements and resource allocation modelling. Currently employed systems would almost entirely have to be labelled as environmental impact evaluation models. That is they deal not only with ecological issues but take an anthrocentric stance. The environmental issues they examine are often as much to do with socioeconomic and political factors as ecological. In most cases the ecological issues are either completely submerged or even eliminated in preference to examining effects for humans.

The use of risk evaluation and uncertainty analysis is a widespread method of decision analysis for environmental impact and resource allocation issues, (*Von Neumann & Morgenstern, 1944; Jeffers & Norman 1978; Quiggin, 1993*) These methods begin with the assumption that we cannot determine what the outcome of ecologically damaging actions will be. From there they use the concept of utility to determine the relative values to humanity of the resource over the notion of a 'pristine' versus a 'somehow damaged' (always unspecified) environment. Such systems are inherently innacurate simply because they deal with possibilities and chance rather than actualities. In reality what actually happens, happens and no amount of chance analysis or prediction will alter or ameliorate the outcome.

The outcomes of humanity's activities are not indeterminate. They are predictable in most cases with a sufficiently broad view and an adequately complex analysis. Risk analysis systems are too shallow in analysis and are still entirely anthrocentric in character. The 'assessable risk' is usually percieved as the risk to humans and their civilisations rather than to the interacting biological ecosystems which make up the global ecology.

Green Cross (Scientific Certification Systems), Green Seal (Environmental Protection Agency, U.S.A.), EcoLogo (Canada) and various other trademarked ecological labelling systems currently sell their services to major manufacturing organisations. These systems each give a form of environmental rating, mostly based on the production of some of the major pollutant chemicals, an energy analysis and a material recycling assessment. To do this they employ the E.P.A., U.S.A.'s Industrial pollution monitoring databases developed over the previous two decades in the U.S.A. along with the widely published results of process energy audits, mostly from the 1970's.

None of these systems attempt an assessment of direct or resultant ecological impact and no effort is made to quantify any environmental rating given. There is no investigation of habitat degradation or biota reduction. No deep evaluation of energy procurement or the impacts involved in transport is made. They are limited in scope and interpretation, taking no account of actual on ground impact or ecologically ameliorating aspects. They are also commercial systems, confidential and unavailable for either academic scrutiny or general use. The use of these systems to inform major resource allocation decisions is as dubious as that of their antecedents, embodied energy and carbon output / fixed carbon assessments. If we are going to be serious about meeting the environmental obligations accepted under the various international agreements thrashed out over the previous few years we must be serious and rigorous about how we assess the cost of procuring the requirements of an enjoyable life.

A serious and rigorous information system must be at least based on the parameters that actually cause ecological impact. It is also critical that ecological evaluation be made in the absence of anthrocentric criteria. The contemporary decision making processes have ample input from humanistic socioeconomic lobbies. The requirement now is for a potent, independent, ecologically based contribution to the debate.

The acceptance of the need for objectivism and the subjugation of subjective analysis is open to critical comment in that it appears to presume the correctness of the current dominant objective paradigm in the intellectual community and disregards the possibility of the value of subjective holistic reasoning, (*Plumwood, 1993*). Resource allocation decision makers, those in positions of power and control, bureaucrats and politicians, consistently call for hard facts and figures and hide behind accusations of emotional subjectivism launched at those criticising decisions. The problem comes in that subjective qualitative evaluations are valid and even essential for relevant decision making for humanity. A balanced evaluation requires both an objective quantitative analysis and subjective qualititative assessment. One way to attack the present dearth of balanced decision making, given the time constraints of the need for action, is to radically alter the current decision making process. As this is unlikely to occur in the near future, it is essential for wide acceptance that any ecologically based evaluation system must operate within the dominant objectively scientific framework of our culture. The need for improved subjective evaluation of alternatives is another area of research.

2.4 A New System

The questions are, firstly, what can we analyse and assess with current data and research, and secondly, what level of detail in evaluation should we strive for ?

It is suggested here that, contrary to widespread perception, the problem in evaluating impacts is not the absence of data, but its availability. Most necessary data is presently in existence, isolated among specialists involved in diverse pursuits. However, with the advent of comprehensive computer networks and powerful operating and data retrieval systems, it is becoming feasible to collect, collate and analyse a wide range of data on most industrial processes from numerous authorities and monitoring organisations. This previously unavailable (in any coherent, accessible sense) data can be directly applied to an ecological evaluation system.

At this stage we still cannot measure the actual ecological impacts of specific processes on particular ecosystems in terms of biota reduction, suppression of vigour and diversity, or lessening the life quality of non-human life, (*Rau & Wooten, 1980*). However, 'surrogate values' based on the magnitude of physical outputs and a reasonable approximation of their comparative impact can be accurately and consistently determined. It is in this area where the potential for further development lies. Previously unassembled data may be used to inform a comparative scale for a generalised assessment of the impact of the procurement process on biomass and biodiversity. These two factors, biomass and biodiversity, are taken as the principal indicators of the health of an ecosystem. Moreover, an evaluation system may be designed so that more intricate factors can be weighed in, as information pertaining to them becomes available.

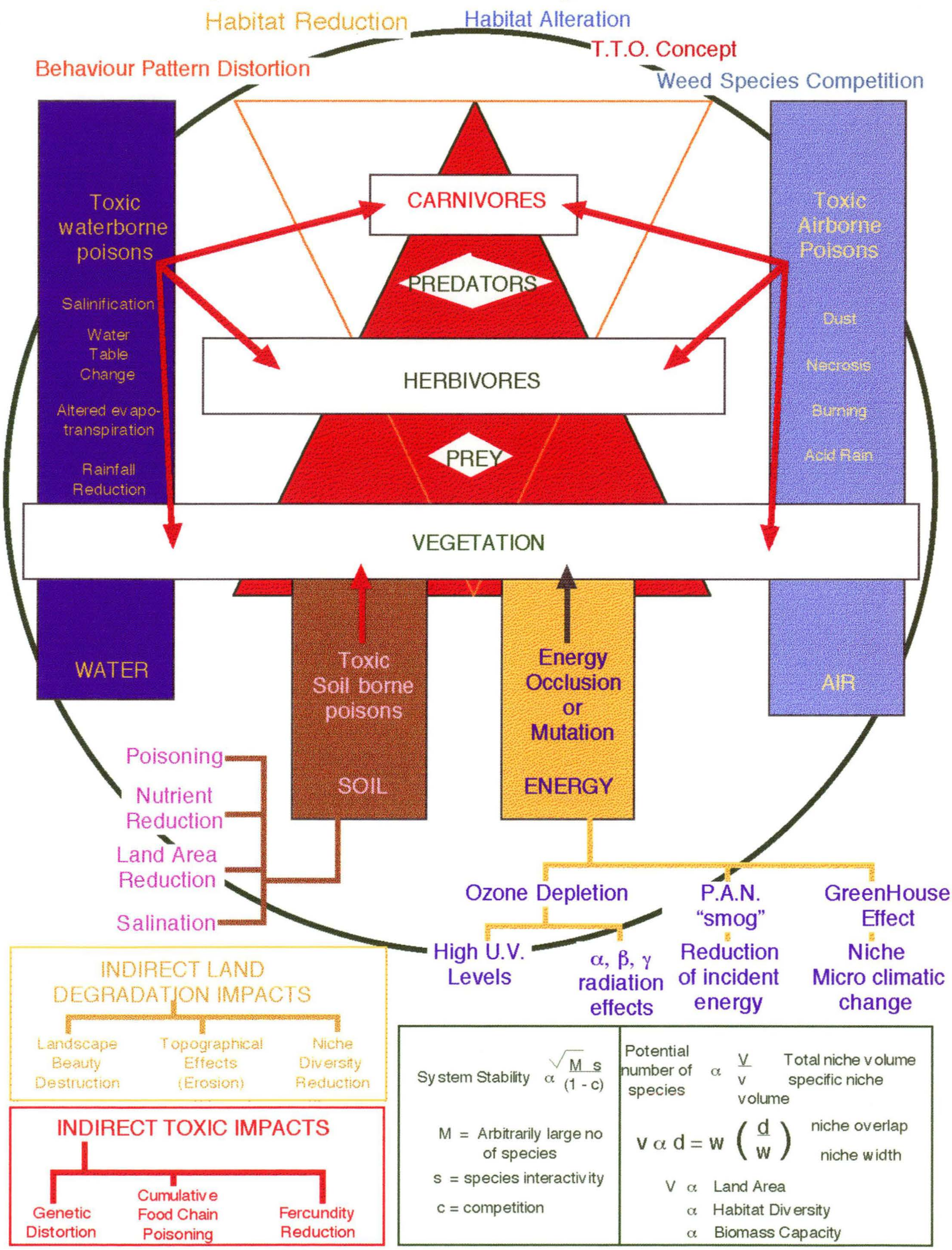
In order to address the immense complexity of the stated task it becomes essential to break the analysis down into components in the traditional reductionist manner in which complex mathematical and scientific problems are dealt with (*French, 1989*). The decomposition of the problem of ecological impact evaluation into its constituent parameters allows the difficult broad analysis problem to be analysed in more manageable portions. The important thing is to maintain a coherent link between the analyses of the individual parts and an overall picture of the workings of the system.

2.5 The Concepts of Ecological Evaluation

A fundamental task of this thesis is to investigate the concept of an ecological cost of materials; the cost to the planet wide ecosystem of using any given item at any given site. This entails an assessment of ecological damage which in turn requires an understanding of what it is that causes the present ecological trauma.

A healthy ecology is one which is in a state of balance having the broadest possible stable range of species in the greatest abundance filling the most diverse niches. Concurrent with the biota are the non living natural forms; mountains, canyons, water bodies, rivers, caves, rocks, cliffs and deserts. These contribute to a healthy ecosystem through the provision of diverse niches, habitats and shelter.

EcoSystems Analysis



e graphic attempts to describe the complexity of the inter-relationships between the actions of humanity and
e functioning of ecosystems and food chains, as discussed in 2.5, Concepts of Ecological Evaluation (pp20),
dividing effects into land, water and airborne toxicants, energy factors and indirect impacts on habitat and
vironmental health. The green box displays the equation forms developed by May, 1973 to describe the
rformance and health of ecosystems.

The basis of the current ecological problem lies in three areas; the reduction of the overall biomass the earth can support, the constricting of the biodiversity of genus', species and ecotypes, and the lessening of the range and size of habitats available. To a large extent the biodiversity can be seen as a function of habitat diversity. It is clear, though, that it has less effect on both biomass and biodiversity to reduce the amount of desert land available than to reduce the area of equatorial jungle; though this may have an equal effect in terms of geographical or habitat diversity (*Roberts, 1985; Margules & Austin, 1991*).

There are two principal actions of humanity affecting the above factors;

- Destruction of habitats.
- Pollution: the toxification of land, sea, water & air;

Habitat destruction reduces both the area available for living species to flourish and also the range of niches. Human activity takes up land area and saps available energy and food sources. Like all other living species, we compete for available resources; when we compete too well other species must be diminished. Pollution reduces the effectiveness of incident energy on the planet, affects climatic patterns and creates toxins adverse to optimal ecological development, all of which reduce the potential for biological success.

2.6 Ecological Impact Evaluation

The development of an ecological impact evaluation system is a complex process requiring a number of steps. Firstly, the impacting factors must be identified; second the impact of each factor needs to be determined; thirdly some form of system to tie all the impacting factors together is required and finally an output that provides useful advice must be developed.

The EcoCost system sets up a framework for determining ecological impact. This begins by identifying all known parameters affecting ecological systems in producing a given artifact. By understanding the manner in which they modify the ecological impact we can then develop a broadly applicable, thorough EcoCost calculation.

The major factors contributing to the ecological impact from the procurement of building materials are;

i) Raw Materials

- The direct environmental damage in terms of degradation of landforms, soils, interference with biota patterns, extermination and dislocation of lifeforms and destruction of habitats, caused by mining, harvesting or growing the raw materials.
- The replaceability and sustainability of the given resource and its reapable limits.
- The level and forms of pollution and ecosystem impacts associated with the capital infrastructure and energy consumption required to procure the material.

ii) Processing

- The impact of the capital infrastructure and energy consumption involved in the processing of the raw material into the final product.
- The pollution and waste generated by the production process.
- The additives, catalysts and other chemicals used in the process and bound into the product.

iii) Transportation

- The impact involved in transporting the raw material to the processing site and the product to the site.
- The pollution generated by transport requirements.
- The land degradation resulting from roads, parking and port infrastructure.
- The environmental impact of the manufacture of the transport capital (infrastructure and vehicles).

iv) Construction

- The application on the site in terms of the energy requirements of fixing, adapting and moulding the product to the desired forms.
- The systems of construction, whether allowance is made for the reuse of constituent materials after the lifetime of the structure has expired.
- Other products required in the fixing and construction procedure.
- The durability of the fixings.
- The strength and durability of the system.

v) Reusability & Recyclability

- The reusability of both individual product and the whole structure.
- The recyclability of the individual product.

vi) Robustness, Longevity & Durability

- The longevity of both material and structure.
- The resistance to wear and tear.
- The retention of appropriateness of the structure.
- The long term pollution or toxicity problems associated with the product.

Steel Roofing Sheet Supply Line

This flow chart traces the production processes required to procure a sheet of colourbonded corrugated steel sheet and associated fixings from the raw materials to the finished product on site, it visualises the information required by the process suggested in 2.6 Ecological Impact Evalution (pp 21 - 22). It graphically depicts the complexity of the investigative tasks required to make valid ecological impact analysis of such products. Numerous ecological and environmental impacts occur at just about every stage of the procedures listed above

3.0 The EcoCost Equation Workings

In order to determine an ecological impact or cost algorithm, a series of operations need to be performed. The first step requires identifying and analysing the factors which directly affect the ecological cost of using a material (those that reduce the potential for biomass and species diversity), and involves determining :

- the area of land and level of degradation involved in gaining the raw materials;
- the toxic output of the process of procuring the resource;
- the process(es) involved in manufacturing the product;
- the toxic output and land degradation involved in processing of the product;
- the transport and energy components and the land degradation and toxic output associated with them;
- a longevity evaluation using the criteria of building life and material durability at the given site;
- additional materials and processes needed for construction;
- proportions of recycled, reused and reusable materials.

There are a series of other factors affecting the EcoCost on an irregular basis which need to be identified, such as, photo-chemical solar occlusion, ozone deprivation, greenhouse effects, specific localised noise problems, visual intrusion and degradation, sustainability of the resource and use of rare or endangered species. Also, positive contributions such as the reparation of existing damaged land areas, energy co-generation and use of waste products should be recognised and evaluated. There will be sure to be more factors that will need to be accounted for from time to time and the above is not an exhaustive listing. A Itinerant Impacts variable is suggested to cope with these important itinerate issues.

A careful analysis of capital versus ongoing impact must be made. This should include a philosophical discussion on how to cost capital ecological impact. Whether an existing facility with low ongoing impact, such as a hydro dam installation, should be used as much as possible to ameliorate the impact or whether the full capital ecological cost (amortised over lifetime production) should be included in the EcoCost assessment, signifying a participation in the original capital ecological impact by the consumption of the resource.

3.1 Parameter Interrelation

3.1.1 Scalar Range and a Consistent Reference Base

Once all the ecologically impacting factors have been identified, a detailed analysis of each factor is required to determine both how it impacts on ecosystems and how the associated impacts can be meaningfully evaluated. The EcoCost system uses a heirachial series of equations, or mathematically speaking, algorithms (given the number of steps and sub routines involved), to evaluate and link together all the diverse impacting parameters. The final linking evaluation algorithm requires that all variables have an inter-relationship which allows them to be mathematically manipulated (added, subtracted, multiplied, differentiated, integrated and plotted) in a meaningful way. For example, the system must be able to meaningfully add toxic impact to land degradation within the algorithm.

In order to achieve a valid mathematical relationship between the parameters, a scalar range related to a constant base entity for each factor is proposed. Choosing a scalar range for ecological impact, between 0 (representing no impact) and 1, (representing the maximum possible impact) allows for the required mathematical operations to be made and describes an internal philosophical validity of global analysis of impact evaluation. The expression of the individual parameter evaluations in a fractional manner eliminates a number of problems struck with previous methods and sets up a framework of analysis with some considerable advantages. It assists in:

- eliminating or cancelling out all units of measurement which is a commonly used mathematical backchecking tool in formula development;
- the addition of impacts from disparate areas cannot be made directly in a mathematically legitimate sense, but becomes valid when the individual parameters are each expressed as proportions of a given maximum impact;
- A fractional analysis follows the evident pattern of the algorithmic expressions, particularly the amortising of effects over the life of product, and;
- Reduces the requirement for a subjective application of numerical values or indexes to unquantified variables.

It also makes it easier to identify and assess any patterns that may emerge from the evaluations, for instance a tendency on a plotting towards 1 is easier to identify than a tendency towards infinity on an open ended scale.

The choice of a single, constant frame of reference for the system is an issue open to debate. Anthrocentricity would direct that impact be measured by its direct affect on humanity, humans and individuals in particular. The use of such frames of reference, I would suggest, is the major fault of most extant environmental impact evaluation systems. Humans, even as the dominant life form on the planet, are not the centre of the global ecosystem, merely a large interrelated segment of it. From a non-anthrocentric viewpoint there is only one single constant which all the various factors of ecological evaluation share and that is the planetary ecosphere.

As recent imagery from off-the-planet journeys has so dramatically illustrated, the globe is finite and clearly bounded. It sits isolated in the vacuum of space with insignificant matter transferal to its surroundings. It has a steady energy gain from incident solar energy from the sun arriving in a broad spectra of electromagnetic radiation, this is balanced by emission of reflected and radiated heat and light energy. The incoming energy is the principal and virtually sole source of sustainable life energy. Through various biochemical processes it is converted into biomass and supports the pyramid of life below, on and above the planets surface. Some of this incident energy is stored in bio-matter both living for short periods and inert for geological periods, but most is lost as reflected and reradiated heat. So, the planet Earth can be seen as a definable constant and sustained reference base for comparative parameter evaluation.

Determining the 'size' of the planet is the next task. It is essential to realise the concept of an interactive zone of the ecosphere. This is the portion of the ecosphere within which the activities of humans have effect. This effect may be through dispersion or dissipation, by either air or water flow or currents, or through the actions of animals, vegetation or geological workings. It is appropriate to take only this interactive portion of the ecosphere as the reference, given the fractional analysis determined above. The ecologically interactive atmospheric volume, land area and oceanic volume can be calculated from available data. (*Cailleux, 1968; Jeffreys, 1976*)

3.1.2 Ecosphere Volume Calculations

The following data has been extracted from various texts on the structure and dimensions of the planet Earth. Various calculations have been made with this data to give reasonable approximations of the interactive atmospheric volume and land area.(*Cailleux, 1968; Jeffreys, 1976; Parker et al, 1978*)

Equatorial Radius (m)	6,378,160
Polar Radius (m)	6,356,778
Average	6 367 469
Total Planetary Surface Area (m^2)	5.10×10^{14}
Ocean Surface area	3.61×10^{14}
Land Surface Area (m^2)	**1.48×10^{14}**

Sea level Earth volume by Calc (m^3)	1.08×10^{21}
Total Earth Vol by calc	1.24×10^{21}
Planetary Mass by Calculation	6.86×10^{21}
Average Density (tonnes per m^3)	5.527
Total Oceanic Volume	1.34×10^{18}

ATMOSPHERIC VOLUME CALCULATIONS

Planetary Volume at sea level	1.08×10^{21}
Average height of interactive atmosphere (m)	6700
Land Surface Area (m^2)	1.48×10^{14}
Average Land Altitude (m)	300
Land Volume above sea level (m^3)	4.45×10^{16}
Active Atmospheric Volume (m^3)	**3.373×10^{18}**

OCEANIC VOLUME CALCULATIONS

Average depth of interactive ocean	850 m
Average Radius at 850m below sea level (m)	6 366 619
Ocean Surface Area (m2)	3.61×10^{14}
Active Oceanic Volume (m3)	4.33×10^{17}

The area or volume of impact for each parameter must then be related to the overall ecosphere volume.

3.1.3 Time

The time factor poses a series of difficult problems, both philosophical and mathematical. Impact, including resource depletion, will always be amortised over time by the self balancing activity of the planetary ecosystem. It is a matter of the time scales employed. The longevity of many artificial compounds, and half lives of radioactive materials can only be expressed in millennia.

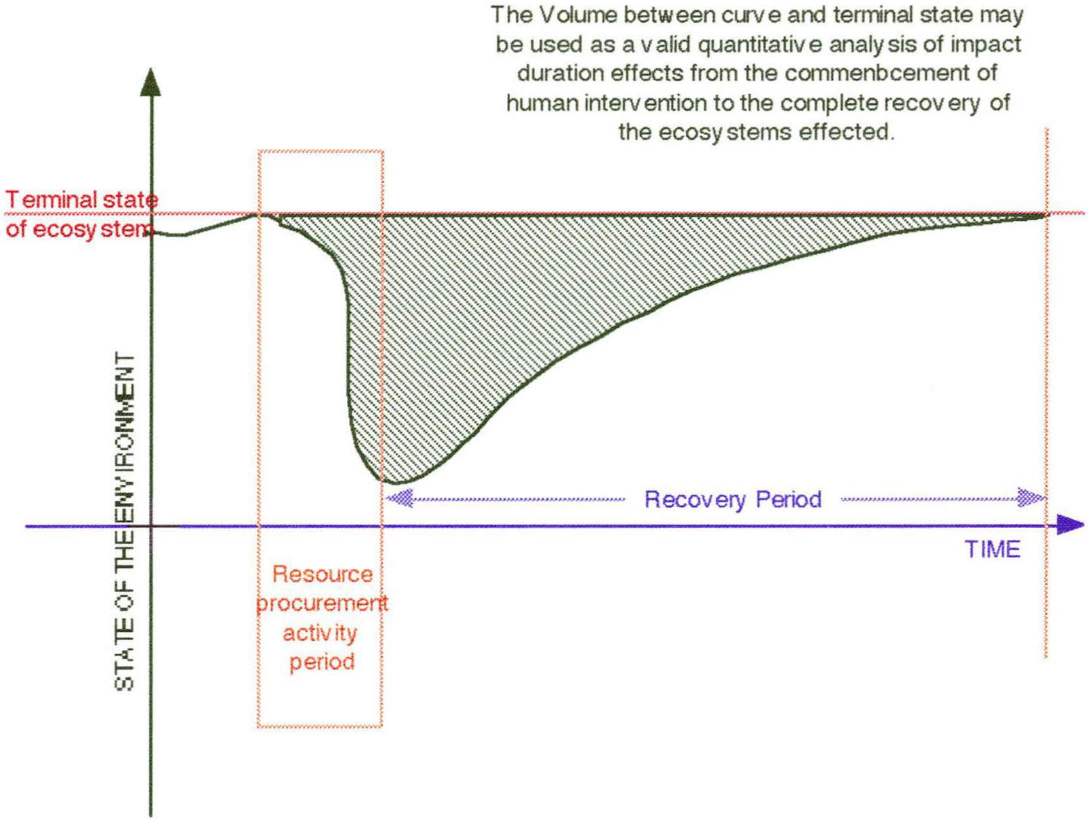
What has to be kept in mind is that with a geological time scale perspective the dramatic short term effects of humanity's impact on the global ecosystem seemingly become negligible. With a human two to five year outlook, impact also seems neglible due to the dispersal patterns employed by our culture. Environmental impact becomes magnified dramatically when examined in terms of a medium term timescale, as our actions take full effect on the ecosystem and resource depletion becomes obvious.

Following the lines of the arguments for employing the global reference base, we must talk in terms of the planetary life span of some 6 to 8 billion years. Incorporating this into the equation is relatively simple by placing a duration of impact amortised over the life of the planet coefficient into each of the parameter evaluations.

$$\textbf{Duration Impact} = \frac{\textbf{Duration of Effect}}{\textbf{Life of the Planet}} \quad \frac{\textbf{(d)}}{\textbf{(Lp)}}$$

The across the board application of the amortising factor of the planetary life will be constant and hence will have no effect on a comparative analysis. Thus the figure actually chosen for the constant of planetary life is irrelevant, removing a potential uncertainty. For consistency the factor must be retained in order to counter the time units of duration of effect.

This time component must then be installed in all parameter evaluations, constituting the fourth dimension of analysis.



Quantitative Analysis of Impact Duration

The figure graphically depicts the quantitative effects of human activities on ecosystems mapped as a function of time in broad approximate terms as discussed in 3.1.3 Time (pp27). The figure suggests that the use of standard mathematical geometrical and function analysis tools may provide a valid ecological evaluation method. This is discussed further in Appx 2.2 Toxic impact State Space Analysis.

Note: - this is a simplistic two dimensional representation, for visualisation purposes only, of a complicated multidimensional state space mapping which demonstrates the approach that may be taken if a valid State of the Environment index is available

3.2 Factor Identification

The next step is to develop an impact evaluation for each parameter related to the available information bases and the global reference base. This involves identifying what information is consistently available or can be determined from existing or readily sourced data and how this information can be used to make an evaluation of the impact on the ecosystem of the particular activity being investigated. If the evaluation is determined as a fractional analysis of the actual impact in proportion to the possible impact and the ratio of the size of the impact to the global reference base this will result in a scalar result ranging from, 0 - no impact, up to a maximum of 1 - maximum Impact total, eternal, global annihilation.

In the EcoCost system land degradation and toxic impact are taken as the principal impacting factors on the health of ecosystems. They each directly affect an ecosystem's ability to support both biomass and biodiversity as well as being determinants of the degradation of non-living natural forms. Most factors of ecological impact, including transport and energy, can be described in terms of their effect on land degradation and toxic impact. Hence, resolution of a viable impact evaluation for these crucial areas holds the key to an accurate, consistent comparative ecological evaluation system. Beyond this, impact is divided into the following parameter groupings:

- Land Degradation;
- Toxic Impact;
- Energy Usage Impact;
- Transportation Impact;
- Longevity;
- Itinerant Impacts (any important itinerate issues);
- The Recycled / Reused nature of the product or process.

Each of these are dealt with individually in the following writings. The linking algorithm for all of the parameters is then detailed.

3.3 Land Degradation Analysis

The localised physical degradation of ecosystems has three distinct faces:

i) the area of land degraded per unit of material/product;

ii) the degree of degradation and;

iii) the duration of the effect until full recovery.

It is nearly impossible to permanently lose land area. Ecosystems have the vital property of being able to colonise virtually any land surface. Time is the principle requirement for recovery. What often gets lost, usually through direct or accidental human intervention is the biodiversity factor. Colonising or artificially replaced species are usually not the same as those in peak or terminal ecosystems. It is important that the EcoCosting take into account the positive ameliorating affects of good land management systems, endemic regeneration and the converse negative aspects of poor land management, introduction of invasive exotic species (both animal and vegetation), unnecessary environmental degeneration and the time taken to achieve full recovery of viable ecosystems after degradation has occurred.

It is important to ensure that land degradation covers both:

i) the gaining of the raw materials, and ;

ii) the land utilised by the processing system or factory.

(Noting that land used by transport and energy infrastructure will be covered seperately under those factors)

Each of these will have a different duration of impact. The duration of effect factor in this case brings into this parameter a recognition of the ecosystems varying ability to regenerate itself or be regenerated at increased rates with human assistance. And also whether the land degraded by raw material gathering can or will be allowed to regenerate at the end of the harvest/mining/gathering activities.

Duration of impact is a complex function of natural recovery and human intervention in both aiding and retarding the restoration of the terminal endemic state of an ecosystem. The plotting of such a recovery curve is discussed in the writings on complex systems analysis of the environment. Time becomes a single vector amongst numerous others in the description of the state of the environment.

In general, given that the ecological impairment of a site reduces as the site regenerates the impact assessment must reduce accordingly. An analysis of the comparative ecological 'worth' of the land during recovery may be made by integrating the recovery curve of the state of the environment with respect to time. In any case, however, to make the analysis prior to the event it is a matter of prediction or guesswork about unknowables. It is here that the mathematics of uncertainty and risk analysis together with complex systems analysis can be gainfully applied to ecological impact evaluation. This area is dealt with in the appendix on potentialities in the section dealing with Complex System Analysis of the State of the Environment.

The area of land degraded and the duration till recovery per unit of raw material should be able to be calculated relatively directly. Figures on land area used and pre and post activity state of the environment reports are becoming increasingly prevalent for major resource procurement activities and will continue to become more so in the foreseeable future.

The land utilised by the processing plant and associated activities will be ecologically impaired for the life of the plant in addition to any regeneration period at the cease of operations. A comparison of a milk production facility and a nuclear powered electricity generation plant demonstrates this concept aptly. The degradation of land utilised by the processing plant can be amortised over the production of the plant either segmentally (weekly, monthly, annually), per unit or over the life of the plant. An assessment of the average duration of manufacturing of a unit of product would give a valid usable duration of effect relating to the particular product being evaluated, ensuring that this includes allowance for the land regeneration period at the end of the plant's life.

Thus land degradation for the purposes of this analysis is an assessment of the degree to which an ecosystem has been altered by human activities, in terms of its capacity to support biomass and biodiversity. Research of available data sources for land degradation analysis reveals a wide range of empirical analysis of actual sites and some interpretation systems (*Marsh, 1978; LoveJoy, 1979; National Parks and Wildlife Service,1980-94; Australian Environmental Statistics Project, 1983; Duncan, 1986; Leslie, 1988; Barrow,1991*).

The available data for land degradation include:

- wide ranging biological surveys for large tracts of public land by public authorities and commissions;
- biological surveys for Environmental Impact Statements;
- biological surveys for 'state of the environment' reports;
- detailed national parks biological surveys;
- annual reports of major resource procurement companies;
- government resource statistics

Ecologically based 'state of the site' indexes for both the post-impact and pre-impact states of affected land areas are sometimes available or can be determined from available information (*Duncan, 1986*). This is a weak area of information and further research is a priority. If such data is available it simplifies the analysis procedure. The impact associated with land degradation will be proportional to the change in the condition of the land from before the impact to after it, or

$$\textbf{Impact} \quad \alpha \quad \textbf{Pre Impact State} \;-\; \textbf{Post Impact State}$$

(the symbol 'α' indicates a proportional relationship)

Given that the biological index for a given land area is a valid representation of its ecological state, then :

$$\textbf{Impact Index} = \textbf{Pre Impact State Index} - \textbf{Post Impact State Index}$$

Because an ecological evaluation is taken to be a function of the ratio of the impact to the maximum possible impact and of the ratio of the area affected to the consistent reference base of the global ecosystem:

$$\text{Impact Evaluation} = \frac{\text{Impact Index}}{\text{Max Impact Index}} \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

It can be assumed that the maximum possible impact would be equivalent to the total nullification of the pre impact state and hence;

$$\textbf{Maximum Possible Impact} \equiv \textbf{Pre Impact State}$$

($\equiv$ symbolises equivalency irrespective of signage+/-)

Thus,

$$\frac{\text{Impact Index}}{\text{Max Impact Index}} = \frac{\text{Pre Impact Index - Post Impact Index}}{\text{Pre Impact Index}}$$

By simple manipulation,

$$\text{Evaluation} = \left(1 - \frac{\text{Post Impact Index}}{\text{Pre Impact Index}}\right) \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

The factors required for this equation are usually known or can be determined from available information and can be quantified relatively precisely and consistently.(*Marsh, 1978; LoveJoy, 1979; National Parks and Wildlife Service,1980 - 94; Australian Environmental Statistics Project, 1983; Duncan, 1986; Leslie, 1988; Barrow, 1991*)

The total ecosphere area can be taken as the land area of the ecosphere which is available for viable ecosystems. (*Cailleux, 1968; Jeffreys, 1976*)

The resulting land degradation evaluation gives a small, fractional, real number ranging between 0 (no impact) and 1 (complete global devastation, maximum impact) as required by the scalar convention adopted above. The evaluation will approach 1 (the maximum impact) as the post impact index approaches 0 or the area affected approaches the total global ecologically viable area. Also the evaluation rises sharply as the total ecologically viable area decreases, reflecting the gradual depletion of world resources and desertification of ecologically viable land. Duration of effect will have a compounding effect and any reduction in the planetary life would create a rapid increase in the assessment.

Some evaluation of oceanic exploitation impact will also have to made as humans turn to the sea for more resources and the effects of land based pollution on the oceans and continental shelves are determined. This will have to take into account the accessible volume of the oceans, interaction with the activities of humanity, available water surface area for incident solar energy and the surface area of ecologically viable ocean floor.

Once the framework of analysis and its associated information requirements are determined it is necessary to find the most appropriate evaluation indexes for both land degradation and state of the environment. Environmental scientists and biologists employ numerous methods of land degradation analysis. The most useful of these require the assessment of the un-impacted ecological worth of the land and a comparison to an assessment of the post impact state of the land. Some of these systems employ a series of written qualitative reports which identify areas of potential impact. Others attempt to give a quantitative numerical valuation to the environmental worth of the area. Both these forms of systems require a series of subjective assessments and scientifically based biological assumptions, in particular with respect to the weightings given to the various aspects of ecosystems. In order to achieve the most accurate, real analysis possible, assumptions and subjective anthrocentric evaluations must be minimised and eliminated wherever possible.

The parameters most widely employed for ecosystem assessment are;

- Biota density
- Biota diversity
- Micro-environmental (productivity)
- Habitat sensitivity
- Rare and/or endangered species assessment
- Rainfall and drainage patterns
- Wildlife corridors
- Significant natural features
- Aspect and slope
- Soil type, structure, depth, fertility and disturbance.

Numerous matrix based systems and some more complex temporally active, network systems have been developed to assess environmental impact but these are confusing to the uninitiated observer and unwieldy for the simple uni-dimensional mathematics proposed for this system.

For the purposes of the EcoCost land degradation analysis it is optimal to have a simple numerical evaluation of the site worth, both before and after the impact caused by the procurement of the resource, to be plugged into the equations. A number of systems have been developed to give an index, or quantitative valuation, to the ecological worth of a given site. (*Lovejoy 1979, Duncan 1986)* The critical point to ensure is that the compatible methods of evaluation are employed throughout the EcoCost analysis to ensure that valid comparisons may be made. The index employed is not as critical as the consistency in employing the same index for each aspect of the analysis or alternatively the compatibility of any indexes used.

The main parameter equation sets up a mathematical situation where various indexes can be used in a compatible way by creating a quantitative proportionality of pre to post impact state.

3.3.1 Land Degradation Indexes

A full description and analysis of a wide range of environmentally based land evaluation systems are given in Appendix Three on Analysis of Land Evaluation Systems.

Amongst the various indexes available there are some representative groupings. Roughly speaking there are two major types: anthrocentric systems which include various socioeconomic and aesthetic factors to determine an overall environmental index; and biologically based systems which use biological indicators to determine the status of the ecosystem.

The Batelle Laboratories of Ohio in the United States of America has developed a method called the Environmental Evaluation System which has been widely employed throughout the USA to give simple numerical evaluations to inform decision making and design, (*Lovejoy 1979*). This system is typical of the anthrocentric types and is heavily weighted with socioeconomic factors, including employment figures and wealth generation for usage proposals.

Another simpler, more ecologically based system representative of the biologically oriented view, has been developed locally by the Australian National Parks and Wildlife Service for their Conservation Assessment Project (*Duncan, 1986*). Called the Biota Conservation Value Index, it has been used in Tasmania and is being assesed for application to land evaluation projects in Victoria, South Australia and Queensland. This system is typical of the biologically oriented systems. The Biota Conservation Value Index system requires some small adaptions to make it usable for the proposed evaluation, and it has some flaws in its assessment methods. These are discussed in the analysis of available alternatives in the appendices. Due to its formal acceptability, basis in empirically verifiable quantitative analysis and reasonably widespread usage, it is indicative of the type of systems appropriate for the task at hand.

Whatever system is used it is important that it be compatible with other systems utilised in order to maintain the relevance and validity of comparative analysis. It is also critical that the systems deal entirely with ecological parameters and (as far as is possible with current data) use empirically verifiable information rather than subjective assessments for determining ratings.

3.3.2 Example Workthrough of Land Degradation (For Energy See Appendix Four for full Details)

(H.E.C.; A.B.A.R.E.)	Coal	Nat.Gas	Dist.Oil	Hydro
Land Area utilised (m^2/GJ)	0.15	0.0061	0.0060	0.240

The land degradation involved in electricity reticulation will require further investigation and has not been brought into these calculations at this stage. It is possible this will be a substantial impacted area.

The small land areas involved in Oil and Natural Gas land degradation make the effects insignificant in the EcoCost system. A closer analysis of the effects of long distance large scale pipelines in sensitive ecologies will be required for improved analysis.

Land degradation analysis requires an assessment of land evaluation (using a land value index developed by the National Parks and Wildlife Service in Tasmania) of pre impact and post impact ecological state. The figures used here are extrapolated from N.P.W.S. and Environmental Impact Statement data sets.

Land Degradation Index Calculation for Coal

Criteria	Calculation	Score Virgin	Score After
Area undisturbed	(212000/50) Max Score (20)	20	0
Naturalness/Disturbance		5	0
Diversity - Species		5	0
Diversity - Communities		3	0
Representativeness		3	0
Conservation Significance - Species			
Threatened		2	0
Poorly conserved		1	0
Conservation Significance - Communities			
Local scale		1	0
Regional Scale		3	0
Statewide Scale		1	0
	TOTAL	44	0
	Biota Conservation Index	44	0

(N.P.W.S. Tas & S.A.)

Post impact index 0 Pre impact index 44

Land Area used = 0.15 m^2/GJ

Planetary Land Surface Area (Total Ecosphere Area) 1.48×10^{14}

Duration of Effect 20 years mining + 30 years recovery

(Simpified figures are used here, this area requires further research)

Planetary Life 4×10^9 years

$$\text{Evaluation} = \left(1 - \frac{\text{Post Impact Index}}{\text{Pre Impact Index}}\right) \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

$$= (1 - 0/44) \times 0.15/1.48 \times 10^{14} \times 50/4 \times 10^{9}$$

$$= 1.27 \times 10^{-23}$$

= 12.7 PicoPicoGaia / GJ

3.4 Toxic Impact Analysis

In order for a comparative ecological impact assessment of toxic damage to be made, some form of assessment of the potential for ecological damage must be applied to each of the toxins which may be involved in the particular industrial process being analysed. The production of toxic substances during the manufacture of materials is the most ecologically damaging factor of our industrial systems in the short to medium term. (*United Nations Conference on the Environment and Development, 1992; Union of Concerned Scientists, 1990*) Nature has a habit of binding up substances toxic to life in complicated inert matter. Humankind has a habit of breaking up hard inert substances to get what they think they need and then tossing aside the detritus including all the released toxins.

Pollution for the purposes of this parameter has been defined as the release of substances into water, sea, air or onto land which have the potential to reduce biomass generation or biodiversity. There is a great deal of work available on pollution control and reduction and (with some reading between the lines) even on toxic output though this is usually heavily disguised by statistical manipulation and obfuscation. (*Meidl, 1972; N.A.T.O., 1973; U.S.A.E.P.A., 1972-78; Parker et al, 1978; Total Environment Centre, 1984; Richardson, 1986; Mickan 1987*) There is little real work or information however, on actual toxic impact on ecosystems of pollutant releases.

The most accurate assessment of impact would entail specific investigations into each individual polluting activity (mines, factories, plants, dumps, vehicles, roads, farms, clearfells, etc.) to determine the actual localised ecological effect of the toxic outputs. This would allow an up to date evaluation of both the short and long term toxic effect of the various pollutants in the particular ecosystem being affected. Such empirical research relies on detailed analysis of biological, topographical and geographical issues, prevailing weather patterns, local biota evaluation, and long term build up problems. This sort of information on the level required, necessitates a great deal of site specific research which is still some way along the track from current political and scientific priorities. The EcoCost system will have to rely on extant data sources.

A number of systems for ecological toxicity assessment have been developed over the last few decades, all of these rely, to a varying extent, on subjective point ratings for the damaging activities of toxins. (*Thomas, 1972; Reiquam 1972; Gallay, 1975*) This makes them inappropriate for an empirically based ecological evaluation system. A new evaluation of toxic impact using existing databases, fitting in with the proportional fractional analysis and relating to the consistent global reference base needs to be developed.

So for the parameter evaluation sub-algorithm, the quantity of toxins produced per unit of production, an associated toxicity rating and the duration of effect will need to be researched. These values for each toxin will need to be referenced to the global ecosystem and given a scalar rating. All the individual toxic effects for each toxin generated by the particular impacting process being analysed can then be summed to give an overall toxic output ecological cost per unit for the product being investigated.

Toxic impact analysis must relate to both the degree of ecological toxicity and the quantities of industrial pollutants, transport exhausts, sewage outfall and other toxins being released into the ecosphere. It should develop an assessment of the effect of such pollutants on the capacity of an ecosystem to sustain biomass and biodiversity.

The known data bases relating to toxic impact of industrial processes from various sources (*N.A.T.O., 1973; U.S.A. E.P.A., 1972-78; Gijutsu & Kenkyujo, 1975; Parker et al, 1978; C.S.I.R.O. 1975 - 92; Ministry of Conservation Victoria 1980; Total Environment Centre, 1984; E.P.A. Aust 1989*) include:

- point source effluent emissions data for water, air and land;
- toxic concentration assessments for health and safety laws;
- probable process emissions for most industrial processes;
- background toxin concentrations for atmosphere, oceans, rivers and land by various government authorities.

Toxic impact is directly related to the quantity of pollutant emitted and the affected volume of ecosphere. The ratio of quantity to volume gives a concentration. The toxic impact evaluation is proportional to the ratio of output concentration to the maximum impact concentration. It is also related to the ratio of affected volume to total available ecosphere volume.

The duration of effect factor in this parameter allows recognition of the planet's ability to 'sink' or biodegrade noxious chemicals.

Through various chemical and biochemical reactions, organic action, dispersion and precipitation, a large proportion of the toxic substances produced by humanity are either broken down or locked away from ecosystems; the automatic self defensive response of the Gaia organism *(Lovelock 1979)*, for those inclined towards that view. The observed duration of effect will vary from site to site according to ecological factors such as wind velocity and directions, topography, local biological action and so on. The overall average duration of effect will, however, be a consistent measurable value for each toxin given that wherever the toxin is and however much it is dispersed it will still behave as a toxin until it is broken down or locked away*(Parker et al, 1978)*. A half-life type analysis resulting in a bell curve distribution, the integration of which gives a quantitative assessment of the interaction of period and potency of activity in the environment for each toxin, provides an accurate evaluation for determining duration of effect. This system is used by many scientific organisations (including C.S.I.R.O. and the Australian Standards Association) to determine a biodegradability or a duration of environmental effect rating for chemicals which can be directly applied to the algorithm, this will require further research.

Meanwhile, given the previous arguments for evaluation systems;

$$\text{Toxic Evaluation} = \frac{\text{Concentration of Output}}{\text{Max Impact Concentration}} \times \frac{\text{Affected Volume}}{\text{Total Ecosphere Vol.}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

and

$$\text{Concentration of Output} = \frac{\text{Quantity of Output}}{\text{Affected Volume}}$$

hence

$$\text{Toxic Evaluation} = \frac{\left(\dfrac{\text{Quantity of Output}}{\text{Affected Volume}}\right)}{\text{Max Impact Conc.}} \times \frac{\text{Affected Volume}}{\text{Total Ecosphere Vol.}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

so, by simple manipulation

$$\text{Toxic Evaluation} = \frac{\text{Quantity of Output} \times \text{Duration of Effect}}{\text{Max Impact Conc.} \times \text{Total Ecosphere Vol.} \times \text{Planetary Life}}$$

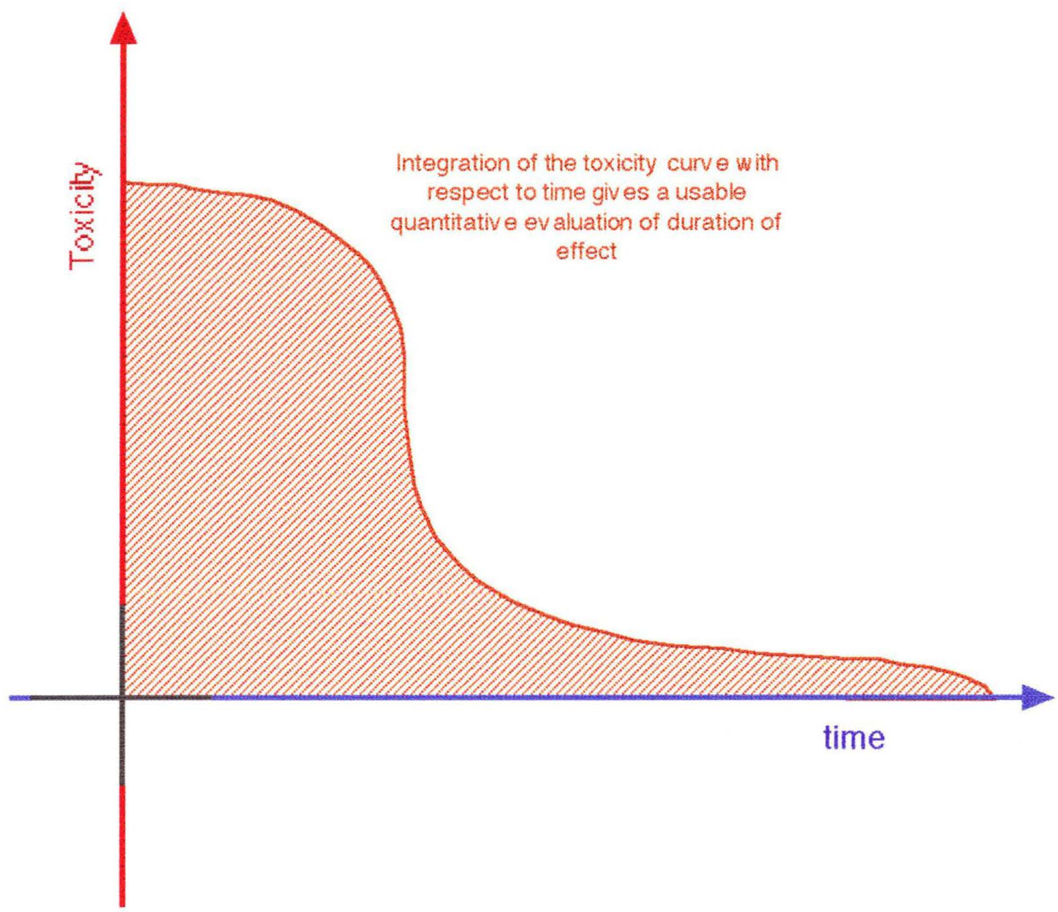
The Maximum Impact Concentration could be determined in several ways. It is important however, that a single method of determining it is employed to ensure the comparative analysis for various materials will be valid. The Maximum Impact Concentration could be taken as: the minimum concentration level at which any biota is killed; the concentration at which no life forms can survive, or; it may be taken as the lethal concentration of the compound or element given by the toxicity rating mechanisms of health and safety authorities. The lethal concentration assessment is determined by a range of 'experiments' on various organisms to determine the concentrations at which death is seen to occur across a range of conditions and lifeforms. The exact figure varies somewhat between species which have different tolerances to the particular toxin being investigated. The range of the lethal concentrations does, however tend to stay within a close range of parts per million for all biota. This figure (or close range) is the only readily available assessment backed by significant broad ranging research, and so it is probably the most reliable fixed reference. It is usually referred to as the LCL_o or lowest published lethal concentration and is expressed in terms of milligrammes (mg) of chemical per m^3 of environment, (*Gijutsu & Kenkyujo, 1975*). By taking the lowest of the range of LCL_o figures given, a benchmark maximum toxic concentration can be generated for the EcoCost analysis.

Due to its cumulative nature, the Lethal Concentration concept has the desirable ability to respond to background chemical levels in the environment. If the background concentration in the ecosphere of the particular toxin has reached a certain percentage of the LCL_o then the extra toxin concentration from the specific polluting instance required to reach the LCL_o will be reduced by that percentage.

Max Impact Concentration = LCL_o - Current Background Conc.

The LCL_o is the subject of wide ranging ongoing research, and so is constantly updated, making it responsive to changes in scientific revelation of the impact of environmental toxicants in terms of both method, duration and potency of effect.

Given that the effect of chemicals on the environment is limited to the interacting ecosphere of the planet, the total interactive ecosphere volume can be worked out from readily available information *(Jeffreys 1976)*.



Quantitative Analysis of Duration of Effect of Toxins

This graphical mapping of toxic impact as a function of time depicts the manner in which the effects of toxic substance released in to the environment decreases as the material breaks down and is incorporated into the local ecosystems, as discussed in 3.4 Toxic Impact Analysis (pp 36 - 40) . Activity of toxins decreases with time (as a rule). The shape of the toxicity curve varys according to the biodegradability and action of the toxin.

Note : This is a simplistic two dimensional mapping of a complex multi faceted effect, it is intended for visualisation purposes only.

This algorithm neatly sidesteps the difficulty of ascertaining the affected volume figure. It recognises that dispersal of toxins is simply a temporary ameliorative strategy and that the chemical must remain in the ecosystem for its given life. A toxin will have a given effect on the ecosystem into which it is released regardless of exactly where it lands and its dispersal. The view must be of a limited enclosed planetary ecosystem, rather than an unlimited frontier world.

It gives as an evaluation a small number ranging between 0 (no impact) and 1 (total toxic overload, maximum possible impact). It approaches 1 (maximum possible impact) as the quantity of output approaches the limits set by the lethal concentration and total ecosphere volume of the planet. The longer the duration of effect of a particular toxin the higher the impact evaluation. The impact evaluation increases rapidly as the background pollution concentration levels approach the LCL_o.

The background concentration could be taken as either the general 'post sink' levels from clean air testing or the air monitoring from the locality of the particular industry. While the clean air testing takes into account the ecosphere's ability to remove harmful toxins from the interactive atmosphere, it probably does not allow for localised build ups of short range toxins, especially with effects such as smog or particulate fallout. Viable point of emission background evaluation would, however, be hampered by a lack of reliable monitoring.

A separate calculation for each toxin emitted by the process needs to be carried out. The total toxic impact evaluation will be the direct sum of the individual impacts for each of the toxins involved.

3.4.1 Example Workthrough Of Toxic Impact (For Energy)

Data: (*U.S.A. E.P.A.; Greenberg, 1979; Parker, 1978*)

	LcLo's	Duration	Coal mg/GJ	Oil mg/GJ	Nat Gas
Particles	985*	days**	633 000	125 000	150 000
SOx	3	months	1.87×10^6	1.1×10^6	8 000
CO	665	days	100 000	30 000	220 000
CO2	3213	years	1×10^8	8.0×10^7	6.0×10^7
HC's	200	days	50 000	25 000	40 000
NOx	103	months	750 000	500 000	2.3×10^6

One GJ of power from a coal burning generating station also results in a solid waste of 0.0048 tonnes of fly ash and 0.0029 tonnes of sulphur ash. Much of this is used in the building industry as aggregate and fill.

Hydro generation may occasionally cause large scale BOD and super-oxygenation of outflow waters though this is an accidental rather than normal effect.

* Some approximation is necessary with unidentified particulate matter, and waterborne suspended solids in terms of the assigned LCLo. Many different compounds are involved and clarification of what these substances are and their associated lethal concentrations is a priority research area. The LCLo's are expressed in mg/m^3.

** Only general approximations of duration of effect have been sourced at this stage, identification of accurate figures for this factor requires further detailed research as a priority. Duration of effect is expressed in terms of years or fractions thereof for the calculation.

Active Atmospheric Volume 3.373×10^{18} m^3

Planetary Life 4×10^9 years

Using the developed formula for toxic impact evaluation:

$$\text{Toxic Evaluation} = \frac{\text{Quantity of Output} \times \text{Duration of Effect}}{\text{Max Impact Conc.} \times \text{Total Ecosphere Vol.} \times \text{Planetary Life}}$$

Toxic Impact Calculations for Coal

Particles

Toxic evaluation = $(633000 \times 0.0192) / (985 \times 3.373 \times 10^{18} \times 4 \times 10^9)$

= 9.145×10^{-28}

SOx = 7.707×10^{-24}

CO = 2.14×10^{-28}

CO2 = 4.618×10^{-24}

HC's = 3.560×10^{-28}

NOx = 9.003×10^{-26}

Σ **Toxic Impact** = 2.133×10^{-23} **Gaia / GJ** = **21.33 PicoPicoGaia / GJ**

3.5 Energy Analysis

Energy consumption is consistently used as an evaluation of ecological impact. Things are not that simple, it should be recognised that the manner in which energy is generated is equally important, if not more so, than the actual quantity of energy consumed. Incorporating an analysis of the actual impact of energy generation into the EcoCost system will allow for the thoughtful selection of higher energy materials manufactured utilising low pollution, sustainable energy sources.

An analysis of the quantity of energy required for any particular process is relatively simple. Detailed energy audits have been carried out for the vast majority of industrial processes and this information can be appropriated and directly applied.

The difficult part is assessing the impact involved in the procurement of the energy consumed. An analysis of the methods of energy generation employed requires the following processes:

- accessing utility supply data to determine generation methods and the proportions that each method supplies to the particular production processes being analysed;
- evaluating the toxic output impact and land degradation of fuel procurement and supply;
- evaluating the toxic output impact and land degradation of capital works for the generating infrastructure;
- evaluating the impact of toxic output associated with the energy generation.

Each of these constituents may then be calculated and summed to give an overall per GJ ecological evaluation, this figure is then multiplied by the energy quantity consumed per unit of product.

The devolution of the energy component into the parameters detailed above (toxic impact and land area degraded, ongoing and capital), gives an assessment of the ecological impact of energy consumption that is immediately compatible with the EcoCost Equation. Figures are available from various sources for this form of analysis of mainstream grid and on-site energy production, (*Environmental Protection Agency, U.S.A. 1972 - 78*).

An aggregated assessment of the ecological cost of the capital plant and works required for the generation of the energy including any post operational effects, should be amortised over the lifetime output of the plant and added to the EcoCost per unit of energy produced. Some risk analysis assessment may be required for potentially hazardous processes (nuclear fision generators and waste products) though this is a complex field in itself (*Von Neumann & Morgenstern, 1944; French, 1989; Quiggin, 1993*) and its applications to EcoCost will require further research. An integration analysis of a plotting of the function of risk against potential ecological effect will be required to give a quantitative assessment of ecological impact risk for the EcoCost system.

Duration of effect of impact is built in to the analysis through the land degradation and toxic impact factors.

The formula for energy impact evaluation becomes a simple summation of the constituent impact parameters:

ie,

$$\text{Energy Ecocost} = \text{Land Deg} + \text{Toxic Impact} + \frac{\text{Capital EcoCost}}{\text{Total Output of Source}}$$

$$\text{Capital Ecocost of Production} = \frac{\Sigma\ \text{Land Degradation} + \Sigma\ \text{Toxic Impact}}{\text{Life of Plant (expressed in MJ Output}}$$

Note: Both the land area degradation and toxic cost should include the procurement, processing and transport to the generating facility of the particular range of fuel sources used in each case.

3.6 Transport Analysis

An analysis of the transport requirement for any process is relatively simple; the particular vehicular form(s) employed are determined and then the road, rail, sea and air distances calculated. Though this does sometimes become convoluted in the marketing operations of many products.

The difficult part again is assessing the impact involved in the transporting. An analysis of the particular methods of transport employed requires the following procedures:

- evaluating the toxic output impact and land degradation of fuel procurement and supply;
- evaluating the toxic output impact and land degradation of capital works for the transport infrastructure and for vehicles, amortised over the life of the infrastructure and/or vehicle in terms of $tonne^{-1}$ km^{-1}.
- evaluating the impact of toxic output associated with the transporting motivator (such as, fossil fuel burning).
- evaluating the ecological impact associated with wastage, used oil, parts, rubber and entire vehicles.

These constituent evaluations are then summed to give an overall per tonne km ecological impact evaluation for each form of transport and then this figure is multiplied by the transport distances involved for each stage of transport and the results tallied.

Duration of effect is again built in to the analysis through the land degradation and toxic impact factors.

Transport Impact $= \Sigma$ **Transport Distances x**

(Σ Land Degradation + Σ toxic Impact +

Σ Capital Impact Motivator + Σ Capital Impact Infrastructure)

or

Transport EcoCost = Td x Σ (LaT + ToT + CeT + CeI)

Where	Td =	Transport distances for each transport type
	LaT =	Σ Land Degradation caused by fuel procurement and operation
	ToT =	Σ Toxic Output Impact of transporting motivator per tonne km
	CeT =	Capital EcoCost of Transporting motivator per tonne km
	that is ;	$\dfrac{\Sigma \text{ Land Degradation} + \Sigma \text{ Toxic Output Impact}}{\text{Life of Vehicle (expressed in tonne km)}}$
	CeI =	Capital Infrastructure EcoCost, amortised over life per tonne km
	that is;	$\dfrac{\Sigma \text{ Land Degradation} + \Sigma \text{ Toxic Output Impact}}{\text{Life of Infrastructure (expressed in tonne passes)}}$

3.7 Itinerant Impacts, β

3.7.1 Indirect Ecological Impacts

The impacting factors discussed above deal with direct ecological evaluations. In addition there are factors affecting the environment which are intrinsically related to the procurement and use of building materials, but which have either a more itinerate nature or a less direct ecological effect. These also belong in the EcoCost equation and must be combined with the more direct ecological impacts. Any evaluation of a factor added into the equation must use the scalar range from 0 (no impact) to 1 (max impact) and the global reference base to allow valid mathematical interrelation and manipulation.

3.7.2 Biological Resource Rarity

An assessment of the impact of using rare and threatened species can be developed by looking at the status of the particular species. The maximum impact for any particular case would be the extinction of the species. This will occur when the population drops below the minimum viable population threshold. The overall impact must be related back to the consistent reference base. This can be done by examining the biomass ratio of the species in question to the overall planetary ecosphere biomass.

$$\text{Rarity Evaluation} = \frac{\text{Minimum Viable Population}}{\text{Number of Individuals Remaining}} \times \frac{\text{Biomass of Species}}{\text{Total Ecosphere Biomass}}$$

For analysis of broader scale multiple species resources depletion, such as forests, a slightly different approach is required, given in the next factor.

3.7.3 Resource Consumption and Sustainability

It must be recognised that while biological resources such as forest and animal products can be managed sustainably, they are not unlimited. These resources have a maximum sustainable rate of exploitation, beyond which they become threatened. An evaluation of the impact of overuse of a resource will be proportional to the ratio of over-consumption to the size of the resource base and also the biomass proportion of the resource in relation to the total ecosphere resource. For non-biological resources an associated ecological impact may be linked to the ratio of resource used to total planetary quantity of available resource (though this is in fact a resource sustainability, rather than an ecological, issue).

$$\text{Evaluation} = \frac{\text{Quantity Consumed} - \text{Quantity Regenerated}}{\text{Quantity Remaining}} \times \frac{\text{Total (Bio)Mass Reserve}}{\text{Total Planetary (Bio)Mass}}$$

3.7.4 Noise

Considerable research has been carried out into the effects of sound on living organisms *(Kryter, 1970; Taylor, 1970)*. This research has found that physical cellular disruption across a range of organisms can occur at particular frequencies and noise levels. Different research lines have identified behaviourally disruptive properties in high noise levels across a range of animative species (*Lovejoy, 1979*). The biological impact of noise pollution can be assessed by examining the ratio of the particular noise level under consideration to the lethal noise level combined with the ratio of the volume affected to the total ecosphere volume and the duration of effect:

$$\text{Noise evaluation} = \frac{\text{Noise Level}}{\text{Lethal Noise Level}} \times \frac{\text{Volume affected}}{\text{Total ecosphere Volume}} \times \frac{\text{Duration of Effect}}{\text{Life of Planet}}$$

This simplistic linear analysis will need further refinement to identify and integrate threshhold noise levels which cause ecological disruption, and the degree to which they have an effect, into the EcoCost assessment. Also particular research into the ecological effects of specific frequencies will be required, and then some method of integrating that information into the algorithm. Multi dimensional state space mapping would be an appropriate technique for such analysis. Such systems are described in detail in Appendix Two on Potentialities.

As a further analysis of the currently proposed equation, noise level is proportional to the energy input and inversely proportional to the volume affected:

$$\text{Noise Level} \ \alpha \ \frac{\text{Energy Input}}{\text{Volume Affected}}$$

and thus

$$\text{Noise evaluation} = \frac{\text{Energy Input}}{\text{Lethal Noise Level} \times \text{Total ecosphere Volume}} \times \frac{\text{Duration of Effect}}{\text{Life of Planet}}$$

3.7.5 Solar Occlusion Factor

Various pollutants, aside from their direct toxic effects, have a detrimental effect on biomass capacity by their action in occluding incoming solar radiation (the principle source of energy for biomass production). Peroxyacetyl nitrates (PANs, a principal element in smog), particulates and sulphates being the most noted examples. Recent work has developed algorithms for evaluating the associated impacts of the actions of these photo occlusive compounds. (*Houghton, 1992; Charlson & Wigley, 1994*) A coefficient of occlusion has been developed for the range of compounds most virulent in this respect. A principal factor in this analysis is the impact of time of effect, these photo-occlusive compounds are short lived, usually a matter of hours from formation until they break down into different non-occlusive compounds.

The analysis gives a burden figure, which can then be modified for use in the EcoCost system by referring to the planetary reference base and applying the scalar range principle.

$$b \;\alpha\; \frac{\sigma M t}{a}$$

or

$$\text{Burden} \;\alpha\; \frac{\text{Occlusion coefficient} \times \text{Mass} \times \text{time}}{\text{Area}}$$

(Charlson & Wigley 1994)

An index of occlusion can be gained by taking the occlusion coefficient and multiplying it by the mass of pollutant involved in the particular analysis. Area of occlusion and duration of effect are much more difficult to analyse and would be case specific for each particular production process.

$$\text{Occlusion Evaluation} = \frac{\text{Occlusion Index}}{\text{Total Occlusion Index}} \times \frac{\text{Area Occluded}}{\text{Planetary Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

Further work or more data is required in order to fully assess this factor and to develop an appropriate assessment for EcoCost purposes.

3.7.6 Greenhouse Effect

The overall consequences in ecological terms of the greenhouse effect are totally unpredictable with current understanding. A large part of the problem is that greenhouse portends change rather than necessarily ecological degeneration. The change has to do with the physical parameters, temperature, humidity, sealevel and so on, to which the biosphere of the planet will then react. It is likely that the nett incident energy available to the planetary ecosystem will actually increase due to a reduction in reradiated energy.*(OECD, International Energy Agency, 1991)* The ecological viability and in particular the biomass potential of the planet is not necessarily threatened by global warming, though habitat change will dramatically alter the species composition of a given area, it may actually increase overall global biodiversity. The rapidity of the change would have dramatic effects in so far as encouraging species movement and the overriding of endemic species no longer suited to the altered habitat, by exotic species adapted to the new conditions. This effect would, however, be global, it could well entail a major migration of species rather than annihilation or genetic adaptation and alteration. Though some habitats and associated species may well disappear altogether.

The EcoCost system, being based on biomass and biodiversity, has a limited and unclear response to greenhouse effects and other phenomena of change. If biomass is increased by the greenhouse effect then it would actually read as a beneficial influence on the ecosystem by the EcoCost system. Reduction in available land area would be balanced off by an increase in highly biologically active warm, shallow sea area. While reflecting an ecological reality of survival of the fittest this does not seem to fully assess the impact of humanity on the ecology of the planet. An analysis of the effects of change on native and endemic ecologies including elimination of certain sensitive, tight niche species, perhaps through Biological Resource Rarity Factor, will reflect a better approach.

It would be spurious to try to quantify such an unknown parameter at this stage. While some form of penalty for the emission of greenhouse gasses should be incorporated into the EcoCost system, it is essential to avoid the imposition of arbitrarily imposed subjective evaluations such as "penalty point scores" or some such device for unknown potential future effects. Risk assessment may have a large role to play in analysis of this unpredictable type of factor.

An extra technical complication is induced by the complicated links between concentration of pollutant and effect. Each of the various gasses which contribute to the greenhouse effect has a limited potential for contributing to heat gain (*Houghton, 1992*) due to the nature of the incident electromagnetic spectrum and the manner in which each particular compound is opaque to some wavelengths and transparent to others. Once this limit of opacity is reached increased concentrations of the given substance will have little further effect on increasing greenhouse problems. However, the introduction of new chemicals having diffent opacity behaviour into the environment may then have a dramatically increased compounding effect to those already at or above their respective opacity limits.

3.7.7 Ozone Depletion

As with the greenhouse effect the consequences of ozone depletion are extremely difficult to predict. Higher incident U.V. levels would, however, definitely lead to a reduction in biomass and biodiversity potential as few species (particularly more complex warm blooded forms) do well in high radiation conditions. A reasonable analysis may be made by determining an index for the transmission of U.V. radiation caused by a reduction in ozone levels caused by pollutant emission.

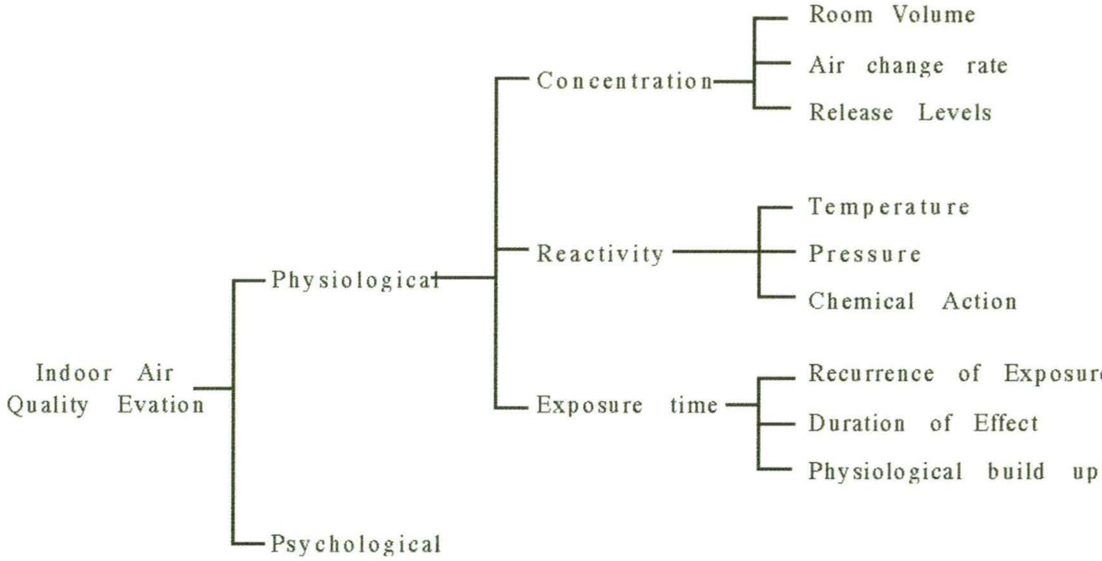
$$\text{Ozone Evaluation} = \frac{\text{U.V. Transmission Index}}{\text{Max Transmission Index}} \times \frac{\text{Area Occluded}}{\text{Planetary Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

$$\text{U.V.Transmission Index} \; \alpha \; \text{Ozone Depletion Capacity} \times \text{Quantity of Polluta}$$

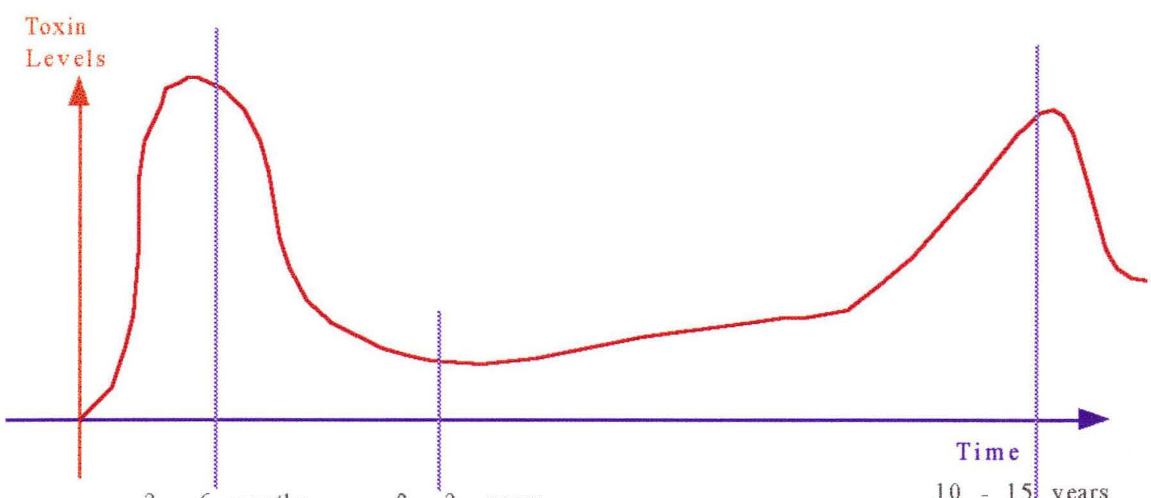
This parameter would probably be better placed within the Toxic Impact analysis of the system where it could be directly related to the particular pollutants causing the effect. Though it is placed here due to the current high profile of the effect.

3.7.8 Indoor Air Pollution

The toxic gaseous build up effect resulting from the use of numerous contemporary compound materials, adhesives and surface treatments in well sealed airconditioned buildings with low air exchange rates has been proven to have a deleterioius effect both short term and medium term for any occupants. This build up of gasses is known as indoor air pollution and is a factor in 'Sick Building Syndrome'. While having a profound effect on material choice, particular for interior finishes, it has



This flow chart depicts a process for the evaluation of impact of indoor air pollution and lists the major areas of effect, as discussed in 3.7.8 Indoor Air Pollution (pp49).



Indoor Air Pollution Analysis

The graphically depicted curve figuratively and approximately maps the toxin output levels in an airconditioned environment with the usual array of materials: Carpets, Composite Boards and Paints, , as discussed in 3.7.8 Indoor Air Pollution (pp49).

Note that this is an extrapolated approximation of a considerably more complex function, it is intended for visualisation purposes only.

little relevance to the EcoCost system due to both its anthrocentric rather than ecological nature and its unpredictability. EcoCost specifically deals with effects on ecosystems of the activities of humanity rather than the effects on humanity of its own actions. There is a distinct difference there and the issues, parameters and methods of assessment are completely different and non-interchangeable.

Post production toxic offgassing is relevant to the EcoCost equations though this is usually miniscule in comparison to the toxic output of manufacture and transport of the material. Due to the dificult nature of predicting off gassing (it being variable according to temperature, humidity, exposure and partial pressure of compounds already in the atmosphere), and the minimal toxic levels in comparison to production it is probably best left out at this stage.

An entire system of algorithmic analysis of the effects of materials on indoor air quality along the lines developed here will require development as an advice system to be used in conjunction with the EcoCost system.

3.7.8 Other Factors

The Itinerant Impacts factor provides a necessary relief valve for the system given the current dearth of good information and extensive research into environmental impact. It is probably inevitable that new knowledge of factors causing environmental degradation will be brought to light over the next few decades, as they have over the last few. In order to maintain relevance and robustness the EcoCost system must be able to incorporate these facets.

There is a wide area for research in this area to clarify the effects of the factors listed and to investigate new factors.

Other factors may be added into this parameter as they are identified and understood by developing evaluation algorithms using the same principles of scalar analysis and relation to the planetary reference base.

3.8 Longevity Analysis

The durability of any material is relative to its location (climatic factors) and degree of exposure to which it is subjected. This is well understood and considerable research has been carried through to determine durability analysis for most materials for Marine, Industrial and Rural exposure. Durability is also modified by weather sealing and surface treatment of materials as well as protection of the material by the form of the structure. The information required for this assessment is widely available from manufacturers and industry research organisations.(*Eldridge, 1974;*)

The longer a material lasts the greater the period of use over which its initial procurement cost can be spread. Initial analysis therefore suggests that the ecological cost of procuring a material should simply be amortised over the life of the material. While this seems indisputable at first glance, a number of other factors come into play which complicate the issue. If a material is not reusable and lasts considerably longer than the purpose to which it is being put then its extra longevity is wasted. If a material lasts for a shorter period than the purpose to which it is being applied then it will have to be repaired or replaced during the life of the structure which should be reflected in its EcoCost of application to the particular project.

By relating the expected life of the material to be used to the design life of the building being proposed in a direct fractional way an appropriate linking of the two factors can be made. The design life of the building should be an indication of how long it will be used (or at least useful) for in terms of the ability of the structure to stand up, maintain shelter and relevance to occupation functions.

$$\textbf{Longevity} = \frac{\textbf{Life of material}}{\textbf{Expected Building Life}}$$

3.9 The Recycled / Reused Factor

The recycled / reused nature of a material has a large effect on the ecological impact its procurement engenders. The principal reduction in adverse impact is through the decrease in new raw materials used, which has an associated lessening in environmental degradation from procurement, transport, refining and marketing. For most so called 'recycled' materials a blend of recycled and new material is common and the recycled material is often either pre-consumer (manufacturing waste) or a blend of pre- and post-consumer material. The reduction in EcoCost is calculated by reducing the overall new material EcoCost by the portion of recycled to new material used and then adding on the EcoCost of the recycling / reusing procurement process for both pre and post consumer material (in isolation from the new material portion).

Impact Evaluation =
(Eco. Impact New Material) x Proportion of Non-Recycled Material
+ (Eco. Impact Recycled Material) x Proportion of Recycled Material

The impact analysis of recycled/reused materials examines the EcoCost of collecting and transporting waste, reprocessing it to a usable base material, making the final product and transporting it to the site. It forms a subset outside the main equation. In effect a recycled material is treated as a completely separate product from a new material. The system thus responds to the proportion of recycled/reused materials incorporated in the manufacturing process and also to the environmental effectiveness of the recycling/reusing process.

A further analysis of the re-usability and re-cyclability of the material in question needs to be made as an addenda to the EcoCost evaluation. This, along with such factors as Indoor Air Pollution potential, will inform further brief decision making beyond EcoCost evaluation.

4.0 The Linking EcoCost Algorithm

The various parameters of ecological impact must be brought together within a process, or algorithm, mathematically speaking, for determining a comparative ecological evaluation figure, this is termed the EcoCost Linking Algorithm. The main ecological impact parameters and the Itinerant Impacts evaluation are treated as simply additive to the impact, utilising the consistent reference base within each to ensure relevance. The simple addition reflects the cumulative nature of the impacting parameters, with any compounding effects being built into the individual parameter analysis and into the Itinerant Impacts Factor

The impact is amortised over the longevity of the material with respect to period of application. The Recycled / Reused parameter can then be factored in, giving the final algorithm.

It is possible with this system that a result greater than unity could be achieved through the addition of the parameter values. This while seemingly implausible, is just a manifestation of humanity's ability to create the now commonly understood phenomenon of overkill. Thus the system reflects the actual empirical situation.

4.1 The EcoCost Algorithm

$$\textbf{EcoCost of Material} = \left(\frac{La + To + Ec + Td + \beta}{Longevity}\right) \times Re + ReE$$

Where

La	=	Σ Land Degradation Evaluations
To	=	Σ Toxic Output Impact Evaluations
Ec	=	Energy Consumption x Energy Production EcoCost
Td	=	Transport Distance x Transport EcoCost
β	=	Itinerant Impacts
Re	=	Recycled / Reused proportion factor
ReE	=	EcoCost of recycled / reused portion.
Longevity	=	$\frac{\text{Life of material}}{\text{Expected Building Life}}$

and

i) **Energy Production EcoCost = LaE + ToE + CeE**

Where

LaE* = Σ Land Degradation caused by energy production and fuel per MJ

ToE* = Σ Toxic Output Impact engendered in energy production per MJ

CeE = Capital EcoCost of Production Plant, amortised over life

that is ; $\frac{\Sigma\ \text{Land Degradation} + \Sigma\ \text{Toxic Output Impact}}{\text{Life of Plant (expressed in MJ Output)}}$

* Both the land area degradation and toxic cost should include the gaining of the raw material, processing and transport to the generating facility, for the fuel source.

ii) **Transport EcoCost = Td x Σ (LaT + ToT + CeT + CeI)**

Where

Td = Transport distances for each transport type

LaT = Σ Land Degradation caused by fuel procurement and operation

ToT = Σ Toxic Output Impact of transporting motivator per tonne km

CeT = Capital EcoCost of Transporting motivator per tonne km

that is ; $\frac{\Sigma\ \text{Land Degradation} + \Sigma\ \text{Toxic Output Impact}}{\text{Life of Vehicle (expressed in tonne km)}}$

CeI = Capital Infrastructure EcoCost, amortised over life per tonne km

that is; $\frac{\Sigma\ \text{Land Degradation} + \Sigma\ \text{Toxic Output Impact}}{\text{Life of Infrastructure (expressed in tonne passes)}}$

iii) Itinerant Impacts, β, is determined from a series of sub-algorithms for each particular case

iv) The Recycled / Reused Factor, Re, is a simple percentage of the recycled / reused portion of the total consumed.

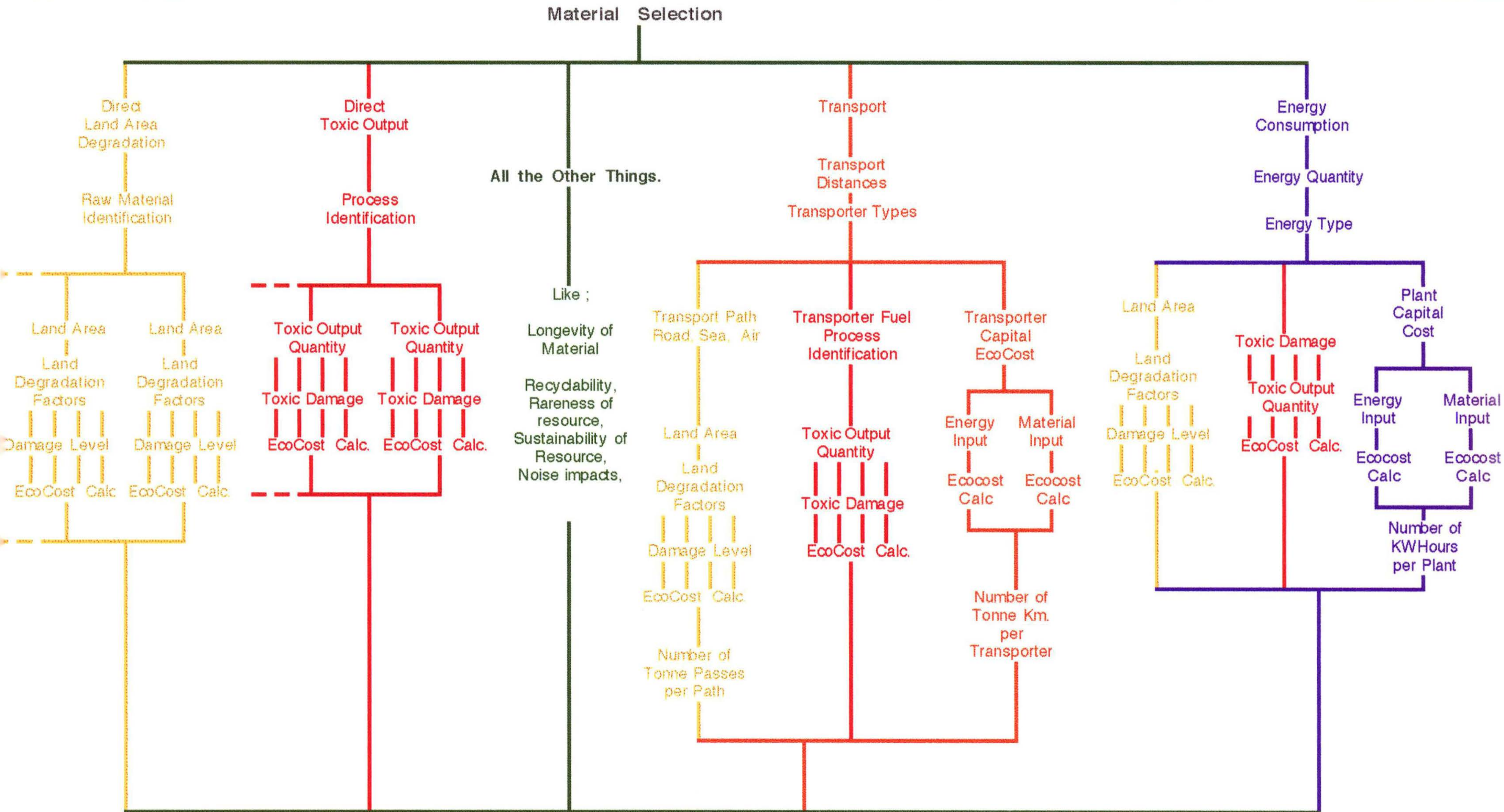
Re = 1 - % recycled / reused

$$Re = 1 - \frac{\text{Quantity of Recycled / Reused}}{\text{Total Quantity Used}}$$

v) The EcoCost of the recycled / reused fraction (ReE) is determined as a full EcoCost equation

$$ReE = \frac{LaR + ToR + EcR + TdR + \beta R}{Longevity} \times \text{Quantity of Recycled/Reused Material}$$

It could be assumed that Land degradation (LaR) would be negligible and Toxic impact (ToR) would be much less than the To of the new material, thus Energy (EcR) and Transport (TdR) become the important constituents for this parameter.



EcoCost Calculation

$$\frac{\text{Land degradation + Toxic Impact + Energy Impact + Transport Impact + Other Factors}}{\text{Longevity of Material}}$$

This flow chart depicts the process of ecological impact evaluation suggested by the EcoCost system. Each flow line requires a separate investigation and detailed data sourcing. The flow chart is a graphical depiction of the EcoCost Algorithm (pp54)

4.2 Dimensioning EcoCost.

An important issue in the EcoCost system is the development of a unit of EcoCost. The system would be enhanced in usability terms by the application of an appropriate unit of measurement. It is important that the system gives figures that can be grasped easily and compared to one another without the need for extensive calculus. Instead of simply saying that such and such has an EcoCost of six or a million or 0.000000000039 it would be much more relevant to give it some form of label or tag and be able to say, this product has an EcoCost of 6.5 $X's$ per tonne or 2.4 $X's$ per m^2

If ecological cost is to be seen as an assessment of the actual effect on the attainable biomass, biodiversity and habitat diversity, then the impact evaluation can be expressed in terms of biomass reduction, biodiversity reduction, the area of land degraded, and the time for recovery (ie, tonnes of Biomass : nº of species : m^2: seconds). Each of these is in turn made up of various other units which would have to be expressed in the final quantification. The outcome of this is an extremely unwieldy unit. A further difficulty arises when we analyse factors for which no units have been designated. For example, we have no units for degree of ecosystem damage for land degradation, it would have to be expressed in terms of number of species, number of ecosystem types, topography alteration, m^2, seconds, and so on. This would necessitate a multi-part result for EcoCost and require complex multiphase mathematical manipulation to generate. It would also require a level of information gathering and processing that is beyond current capabilities. It would also pose a real problem to users who have some difficulty with double digit accounting to have to face up to multiphase systems mathematics ! Although this would be a very real ecological cost assessment, it is a very unwieldy dimensioning system that will have to await future development.

The EcoCost system as it is proposed here gives a high level approximation for comparative purposes of the actual ecological cost in a single vector quantified result. As part of the mathematical requirements for valid manipulation, the system has been developed to eliminate all units from the parameter evaluations. By doing this the final result has no units attached to it, it is an expression of impact on the ecosystem per unit of material being analysed. An exciting and joyous proposition is to use the term *'Gaia'* as the unit of EcoCost. Gaia is the name proposed for the concept that the planetary ecosystem has an apparent capacity to act as single organism, (*Lovelock, 1979*). It is not pronounced that the planet is a single cogent living entity, simply that due to the complexity of interactions between the myriad activities on the planet that it can be better understood by analysing a model based on the assumption that it does function as a single complex organism. The use of the term, Gaia, in the EcoCost system can be justified by examining the proposed scalar, comparative system. The maximum impact of one is equivalent to the ecological devastation of the globe, if you like the termination of Gaia. It thus seems appropriate to have the maximum impact of 1 as One Gaia, then normal levels of impact may be measured in MilliGaia, PicaGaia and so on.

As the EcoCost system is under continuing evolution and will probably continue to be so for some time it is essential that the unit be related to the particular version of the system being employed. A dating should be included in the final unit terminology. As the EcoCost of a particular product and materials in general will also change acording to the manufacturing and raw material procurement processes being used at a particular time the allocation of a date to the EcoCost unit becomes increasingly important.

As such it should be referenced to the time in which the analysis was made. An EcoCost evaluation made in 1994 for a particular material for a particular site would not have the same result as an EcoCost evaluation made for the same material at the same site at a different time, say 1996. This reflects the changing ecological state of the planet as the base reference for the evaluation algorithms, both in terms of toxic element background levels and intereactive ecosphere volumes and areas. The same situation applies for the particular material at a different site in 1994, it will have a different EcoCost evaluation. This then leads to the possible necessity of having results of the form of:

EcoCost (F14 S.H.W. 90x42mm Clearfell Eucalypt, Kiln Dried, Central Hobart, 1994)

= *(say)* **1200 PicoPicoGaia per lineal metre**

5.0 Interpretations

5.1 Question One. Does it work ?

Well of course it works ! But apart from that ....

5.1.1 Validity of Parameter Equations

The simplified functions used to determine the EcoCost parameters are approximations of the actual situation based on the limits of our understanding of the problems and causes at present, the actual relationships would be extremely complex multi variable functions. The multi-phase functions required to describe the actual relationships between variables and impact are not known at present and will take a quantum leap of understanding to identify. However, the proportional relationships developed here provide an adequate high level approximation of the impacts involved and can be used to develop the overall algorithmic framework for the EcoCost system. More accurate (real time / real world) equations and functions for the various parameters may be substituted into the EcoCost algorithm when they become available. The important thing with the EcoCost system is that an appropriate logic for validly interrelating the parameters has been developed. The weak areas of information requiring further research have been identified through the thesis.

The manner in which the parameter equations respond to changes in the variables indicates that they are reflecting the actual ecosystems reasonably truthfully. Closer examination and empirical testing of the system could well lead to further refinement of the simplified relationships developed here.

5.1.2 Falsifyability

Falsifyability is the catch-cry and safety valve of the scientific method. To be classified as scientific, a theory must be able to make predictions which may be tested experimentally. If such predictions are verified then the theory is supported (not proven), if predictions are not verified, then the theory is disproved and must be revised or discarded. (*Hume, 1777; Popper, 1968; Tarnas, 994*)

This system of ecological evaluation is capable of making predictions about real world events and impacts. By utilising the fixed reference of the planetary ecosphere throughout the parameter analysis equations they automatically have an valid inter-correlation with the world around us. The system also ensures that simple mathematical manipulations using the parameters in combination are justified and a logical integrity is built into the system.

It is essential when dealing with a subject as complex as ecological evaluation that predictions are made which can be tested by the resources and methods available. The EcoCost system should be testable and falsifyable by determining ratings for two specific products (making predictions on associated impacts) and then carrying out a series of on-ground biomass and biodiversity analysis for before and after the impacting events associated with the procurement of the given products. The higher EcoCost product should cause a greater level of biomass or biodiversity depletion. A number of specific on ground tests along this line could be carried through to provide valuable correlation or critique of the system.

5.1.3 Interpretation

In order to give a frame of reference to the EcoCost evaluation and EcoCost budget for a particular project, some interesting comparisons may be developed. For instance, the EcoCost value equivalent to the extinction of a particular biota species could be calculated as a reference line. This would enable a comparison of the sort that; "...the EcoCost of a particularly massive construction would equal the extinction of this species." While such a comparison is verifiable with this system, observation would suggest that it is a dramatic overstatement. Observation, however, never sees the full ecological effect of action condensed into a particular event, it is usually widely dispersed and to a large extent hidden by this dispersal. To make such a statement would be extremely contentious and create strong feelings of antagonism and a degree of division between pro- and anti- development lobbies, so the wisdom of doing this may be questionable. It would however bring to light the hidden effects of our actions, we have after all directly caused the extinction of numerous species over the last century.

Our society has developed ingenious methods of hiding our wastes and mistakes. We bury them in holes, disperse from lofty chimneys, dump deep in the oceans, incinerate at high temperatures, we are even contemplating shooting off into space the toxins we produce (*NATO, 1973; Guess & Huismus, 1983; Air and Water Waste Management association, 1993*). Whatever we do with these toxins they are still going to have an effect on the ecosystem, at some place and time. The true impact of our actions must be brought to light to allow informed decision making. Any workable empirically based evaluation system is better than the current situation of no advice at all.

5.1.4 Professional Responsibility

Ecological evaluation systems are not substitutes for diligence on the part of the designer or specifier. They are guides which put the designer in the ball park. The designer must address all the other issues of environmentally sensitive and sustainable design including efficiency of materials, structure and space, robustness, longevity of the structure and appropriateness of the design.

Specifications must be followed up rigorously to ensure that the specified products are arriving from the proper source in the right way and are being utilised in the designated manner. A new professional specialisation is emerging in the specification, procurement, distribution and proper employment of environmentally benign materials. This profession will require systems such as EcoCost.

A great deal is being made these days about professional liability and responsibility. I wonder if, in the not too distant future, this is going to take in such issues as indoor pollution, toxic material use and even environmental impact of buildings and material consumption. A professional's responsibility or "duty of care" to employ the best accepted practice in designing a building is the basic tenet of these claims, it is conceivable that a practitioner may be sued in a class action in the name of Gaia for wilful desecration of the environment by irresponsible material selection. Sounds far fetched, but think back even ten years to what was and what was not considered sue-able.

5.2 Question Two: What does it mean ?

5.2.1 The Impact of EcoCost on Architecture.

At present there are two opposing forces to the effect of environmental issues on Architecture, both of these are due to the attitudes of Architects. There are those who treat ecological issues as a prime concern and inform their designs appropriately and there are those to whom it is a subsidiary issue which does not impact on their architecture. Then, as a sideline, there are the weaker designers who pastiche on, as the fashion of the times may dictate, various ecologically sound imagery without any coherent reasoning process.

For those to whom environmental and ecological issues have some importance, this work will provide a useful tool. The potential of ecological evaluation systems for altering the way in which architecture is practised is high. It has been suggested that an ecological or environmental 'style' may well emerge. Some even say it has already crystallised. As with the diverse, complex and indefinable nature of ecologies, the imagery and formal structure of ecologically sensitive architecture is too dispersed and variable to identify as a coherent iconography. The intrinsic validity for labelling these works as ecologically aware comes from the philosophy, thoughtfulness, breadth of understanding of and sensitivity towards environmental issues that inform the design. As with an ecology; diversity, originality, unpredictability, lightness and a plethora of layers of careful, finely, resolved detail provide the essence of beauty in the best of these designs. The telling factors are desire for a natural setting, sensitivity to the place and delicacy of siting, fitting in with the least disturbance and the greatest harmony while still managing to make necessary statements on art, culture and place.

This is fine as far as it goes but it has never been the small, carefully thought through pieces of architecture that have created the environmental disasters which plague us at present. It is the large, indignantly consumptive, commercially oriented structures that cover our cities and plains like some noxious fungus that cause the predicament. These, in the current way of things, are the principal realm of the ecologically insensitive. There are many people who see the issues of sustainability as some sort of sideline from the main game of economic growth. The self delusion and lack of understanding of reality embodied in this attitude is profound. It is with the mainstream economic rationalist developers and in the creation of their broad acre developments and megastructures that I hope this work may have some effect. Lifting the base level of environmental performance by a few degrees across the board will have a far greater beneficial effect on our ecosystems than simply improving best practice. By providing a system which in external imagery (though most definitely not in essence) resembles the current modus operandi but which facilitates an ecologically beneficent attitude, the current paradigm may be subverted. If EcoCost can be made acceptable to mainstream practice in the tight commercial design environment its effect will be profound.

The availability and common acceptance of ecological evaluation systems may also provide an operational basis for those whose commitment and philosophy otherwise inhibits their involvement in the high consumption world of the commercial building industry.

5.2.2 Stylistic Issues

Will EcoCost either directly or by default engender a style ? A materials and construction form driven style similar to the mud brick, pole frame, rammed earth, stained glass, passive solar imagery of latter years. I believe not, I certainly hope not. There is perhaps not even a coherent 'style' in this area today, but a conglomeration of numerous stylistic influences, imagery and formal paths grouped together under a banner of mutual philosophical committment to a reduction in environmental impact. Other than this central tenet they have diverse aesthetic and philosophical sources.

Styles are anathema to thinking, they allow the process of design to be subjugated to preconceived notions, whose relevance to the place and particular project is questionable at best. They allow the tracing of imagery and iconography without contemplation, relevance or even conviction.

The pigeonholing of ideas and philosophies into design 'styles' allows dismissal of those ideas with the images and icons of the style. Simply by claiming a dislike for this pediment or that sprung roof the cynics can renounce themselves from the burden of responsibilities engendered by the perceptions of the thinkers of the philosophy which led to the style.

EcoCost will determine that a certain range of materials will be more appropriate to a particular place. While the acceptance of this will lead to a materials driven contexturalism and a structural minimalism, EcoCost has no dictates to make to formal or planning issues.

If a philosophy is removed from any and all particular formal styles, its worthiest notions can be adapted by the followers of any creed without compromise or perversion. Its message has a real chance of achieving universality without prejudice. EcoCost takes a philosophical point of view and explores the ways in which this can be reflected in the materialistic world of building creation. Using the EcoCost system is the result of a conscious choice, requiring some effort and a deal of understanding of the issues at stake. It is not simply a design style handbook or style generation rule. It seeks to inform but it levies an effort of the user, it demands responsibility and strives to engender it.

I see this ecologically based costing system as above (or, if you prefer, below) styles and imagery. It is part of the process that informs sensitive design, part of brief generation. I would hope that the ingenuity of designers would allow them to take whatever are the most ecologically sensitive base materials at hand and develop them into a finished building with their unique desired imagery, form, structure, texture and finish. Constraints are the dough andwit is the leavening of fine architecture. This is the challenge of sustainability for architecture.

Given the diversity, range and capability of contemporary technology and its rapid and multifarious growth it can be expected that new low EcoCost materials, products and processes will start to take over from the current batch of consuming, polluting, insensitive stock once the pressure from consumers becomes great enough. Technology if directed with the appropriate parameters is very capable of solving many of the problems it has created through its indiscriminate, unbridled application.

So, the impact of the EcoCost concept on Architecture? Insidious, subversive, temporarily destabilising and I hope profound.

5.3 Question Three: Which materials are best ?

This is the question everyone asks and it is the hardest to answer. The simplest answer is it will vary from place to place and according to the particular situation.

To answer the question will require that the EcoCost algorithm be carried through for each material at each particular site. To go through the extensive procedure for the evaluation of each and every product, item or material being used in a building programme is a daunting task, perhaps an unrealistic expectation. It should, however, be possible to carry out EcoCost analyses for the major distribution centres throughout the country and let the enthusiastic do the further resolution.

Even this may seem like a gargantuan task, but it is a task that must be undertaken. So many of the requirements of green economics rest on the assumption of assigning value to non-economic realities. "Internalising, externalities", as the economists so clearly put it. Most of the profound errors in science, philosophy and architectural practice have been generated by reliance on incorrect initial assumptions. All too often dubious assumptions of ecological impact are used to launch pyrrhic campaigns comparing options as to the best, most 'green' solutions. This thesis demonstrates that it is not only possible but eminently feasible to develop a reliable, consistent and repeatable assessment of the suitability of any given material for any given site. All it takes is the will to get it done.

One would hope that an EcoCost type evaluation would eventually be a part of the marketing criteria of all products and the evaluation process would be the responsibility of the manufacturer. Even further down the sociopolitical evolutionary line the EcoCost of a product would actually become its given value, and the monetary system would be based on ecological principles, and sustainable resource consumption. Thus the dollar value of a product would directly reflect its EcoCost.

5.4 Principal Findings

5.4.1 Some Musings

By analysing the EcoCost Algorithm various principles become obvious without the necessity for actually working through all the detailed calculations on all materials. By isolating a single parameter and holding all others even, a comparative analysis may be made of the effects of particular cases on the overall EcoCost of a material. By adjusting individual parameters, interesting general guidelines for assessing the relative ecological impact of using various materials become apparent.

Some preliminary examinations of the workings of the EcoCost algorithm demonstrate the following principles.

5.4.2 Transportation

Initial calculations using limited available data show the importance of transportation in the selection of low ecological impact materials. Very high impacts result from toxic output from fossil fuel burning for road vehicles and the land degradation associated with roads and infrastructure. Any material which can be gained from the site, processed on site and erected on site has an immediate EcoCost advantage. The closer the source of raw materials to the processing plant and to the construction site, the more ecologically sound the product (all other things being equal). The green philosophical issues of contextualism, endemic characteristics, the practical problems of quality and process control in terms of impacting processes also favour local materials and on site manufacture.

From the preliminary analysis of toxic output and land degradation parameters with the EcoCost system (see the example workthroughs in the appendices), sea transport is considerably less damaging than rail which is an order of magnitude less impacting than road freight. Although it is often extremely difficult to properly specify a particular transport regimen it may be that this will become a priority for environmentally aware design in the not too distant future. Thorough analysis of the range of transport types within the general categories of road, rail, sea and air freight will give further insights into optimum transport regimes.

Another major issue (which is not taken into account by the EcoCost system) is the transport requirement for labour during a construction process. Given the enormous EcoCost of personalised transport this cost has the potential to outweigh the material EcoCost of a structure. This analysis should be a part of the EcoCost budgeting process rather than the EcoCosting of materials.

5.4.3 Longevity

The longer a material lasts, the more the procurement cost can be amortised over the materials life and hence the lower the overall ecological impact. Matching the material lifespan to that of the proposed building gives a break even point. Materials that last longer than the building should be viably reusable or recyclable. Materials that do not last as long as the building, will have to be replaced at some stage, which dramatically increases their EcoCost.

5.4.4 Energy

Many consider energy consumption a useful indicator of environmental damage. This stance, while in most cases valid, has a few pitfalls. It is fallacious to say that energy consumption is in itself damaging to the environment. There are many ways of generating energy. If the energy is generated in a clean, non polluting manner as a renewable resource, then its environmental impact will be much reduced.

Embodied energy has come to be used as a full environmental evaluation, not just as an indicator of potential for damage, this must be remedied. The EcoCost system provides a much wider, more thorough and realistic analysis of the impact of the use of energy.

Numerous energy sources of considerably lower ecological impact are now appearing. Renewable energy sources such as hydroelectricity, wind generation, direct solar collection, wave power, biological methane gas, ethanol and so forth are becoming viable alternatives. For instance, where power is generated through dispered wind generation, the initial construction of turbines has a moderate EcoCost and alters habitats, at least to some extent. This can, however, be amortised over long periods of non polluting, non-consuming operation. This allows for a much lower EcoCost of high energy products manufactured with the use of this energy.

This can add an interesting twist to the EcoCost assessment of various materials. For instance a high energy material such as aluminium produced utilising clean low EcoCost energy sources, for manufacture, profiling and use in the same locale, would have a considerably lower EcoCost than the same aluminium requirement produced with coal fired electrical power and then shipped to the site from a remote source. As both refineries may well be owned by the same conglomerated corporation who pool all their production for further refining, machining and distribution and have no means of separating material flow, it becomes very difficult to order the local low impact aluminium for local delivery. But the more times an unusual product is precisely specified the simpler the acquisition system becomes.

Many high energy consumption materials are in other respects low in environmental and ecological impact. They often use less resources, are stronger, less toxic and more durable than moderate energy, heavy resource using products. By showing major energy consumers and manufacturers of high energy products that there is a way out of being considered environmental degraders, it encourages them to alter their energy supply systems to become lower impacting users. Getting away from the falsely assigned direct link between energy and environmental impact is critical to environmentally benign technological and material development in the medium term future.

5.4.5 The Specific Nature of EcoCost

The location of the works, the chosen product sources and the specific method of manufacture employed are all critical to the resultant EcoCost of a material. The structural system, construction techniques, design life and finishes all work together in complex patterns to influence the overall EcoCost of a building. As a generalisation; minimalist, self sufficient buildings constructed for specific purposes close to the users, made of local materials with as little transport of materials and labour as is possible produce the optimum EcoCost budgeting outcomes.

5.4.6 Structure

It will require a lesser amount of a stronger material to perform a given structural act than of a weaker material. To take an example, steel would most likely have a much higher EcoCost per tonne than well harvested timber but for long span members and more efficient structures (trusses, spaceframes) where much less material is required to perform a given task, steel starts to make ground in terms of ecological cost economy, even given the extra energy required for construction. Accurate analysis of these assessments require an engineer and quantity surveyor, but good approximations may be made by a designer using spanning tables, the mass per metre length figures and the EcoCost calculations, all of which should be readily available for various materials.

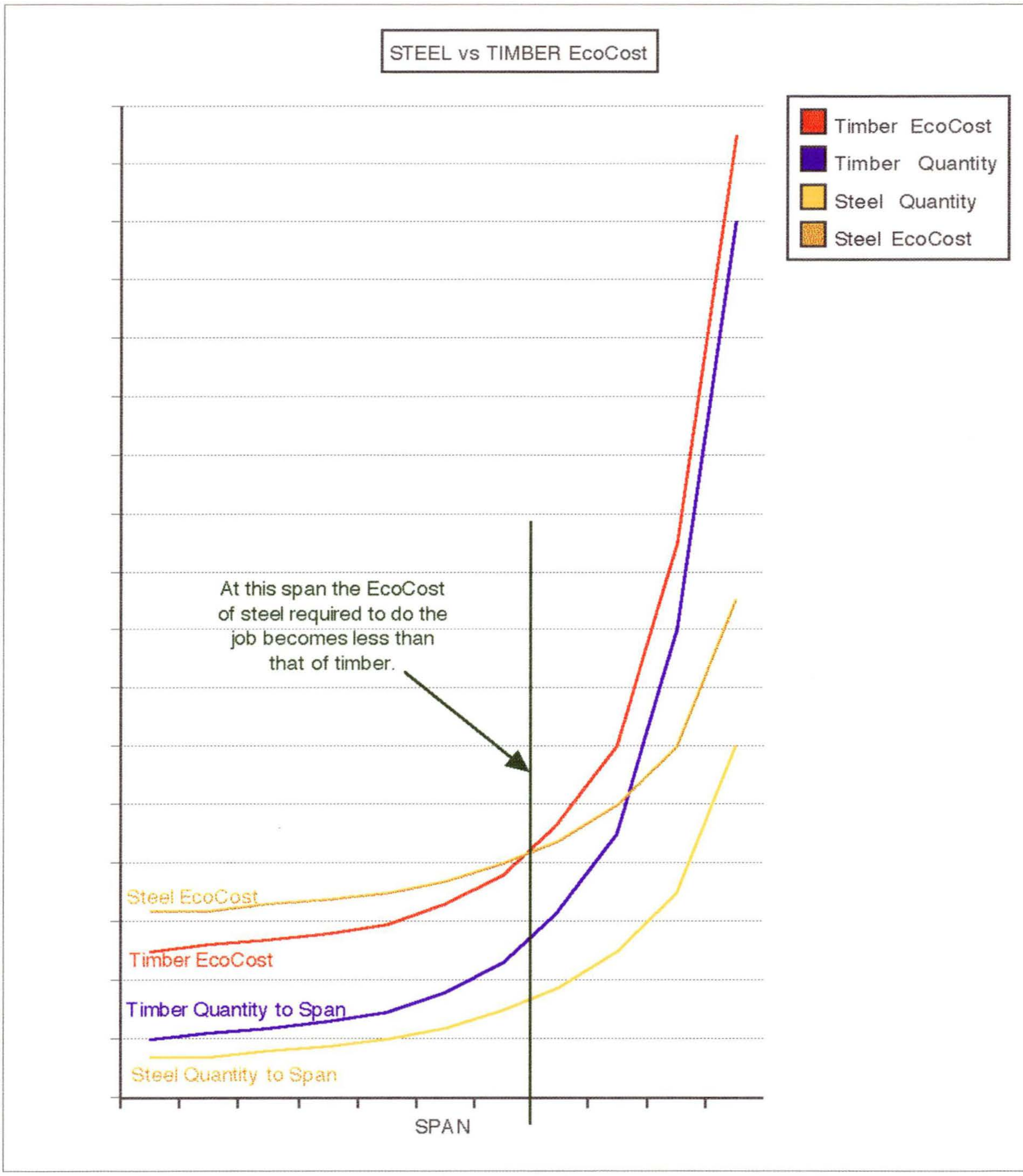
The crossover points for different material's span versus EcoCost capacity will be important to identify as it would have a profound effect on built form and structure options.

5.4.7 Construction versus Operation

A comparison between the ecological costs of employing energy efficient materials and systems against the ecological impact saved by the reduction in energy consumption may give interesting findings. Energy capital versus operating consumption calculations have been carried through in great detail, but they have failed to take into account the manner in which these completely separate energies are generated and the associated ecological impacts. It could be that the EcoCost of triple R52 reflective solar glazing with its associated neoprene gaskets, silicon sealing, inert gasses and aluminium framing may well outweigh that of a wind powered electric bar radiator for a considerable period of time.....

5.4.8 Boundary Conditions of Analysis

How detailed should an analysis be? One must draw the line before worrying about, "where was the bratwurst that the workers in the plant had for lunch last Tuesday made?" Some form of assessment of our actions in environmental terms is required, however crude, to guide us toward the least destructive path available. The resistance to using non-anthrocentric costing systems is deeply ingrained in our



Steel vs Timber Span & EcoCost Graph

This graph figuratively indicates the effects of strength versus spanning capacity for two different materials as discussed in 5.4.6 Structure (pp 67), in this case steel and timber. It shows the flux point at which the Ecocost of the steel required to do the job becomes less than that of the much larger quantity of timber required. This would be a material choice transition point.

decision making institutions but must be overcome to achieve any real progress in the move to achieving sustainability. Environmentally concerned designers while accepting that an ultimate system is not yet available and continued effort must go into developing better systems, should be keen to have at hand any reliable information system to aid their decision making. The trade off will always be between accuracy and depth of the system versus its day to day usefulness.

5.4.9 Approximations

The level of approximation or subjective application of value required to gain usable results for these calculations is another matter. Any approximation is by definition dangerous as it relies on the proficiency of the approximator. One can simply hope that continued research and the constant raising of awareness will increase the levels of information available and consequently lessen the need for extrapolated approximations and guesswork. The ecological evaluation devices proposed for complex systems analysis of the state of the environment (see appendices) will go a long way to reducing the need for approximations and assumptions.

5.4.10 Using the System

This system is intended to inform the brief for the design, it should be used to identify the most appropriate palette of materials for the particular site, job and time.

While the concept of ecological evaluation processes is still in its infancy, widespread consensus on the appropriateness of a particular system is unlikely to occur without extensive debate. Through constant critique, scientific testing, revision and peer review the available systems come closer to their stated goals. The validity and wider acceptance of any ecologically-based evaluation system will depend on an active dialogue with prospective users of the system and academics, intellectuals and practitioners concerned with problems of resource consumption.

Another area of contention, is the nature of the interface between the practitioner and the information. Very few designers, architects or specifiers will want to be involved in extensive research or a complex series of calculations. It is vital that the system present the information in clearly defined, easily accessible terms and formats. To this end, the EcoCost research proposes the development of a handbook of EcoCost evaluation, containing location / EcoCost matrix tables giving a base EcoCost for materials at their local distribution centres. An interactive on-line computerised information service with an 'expert' EcoCosting system making use of new developments with 'agent' type software should also be developed to constantly gather data, interpolate it and process it into useful advice for designers.

5.4.11 Change.

An awkward aspect of the EcoCost system was revealed in the analysis of the greenhouse effect on ecosystems. EcoCost is not particularly sensitive to large scale, long term changes to the ecosphere which maintain biodiversity and biomass but which alter habitats, niche conditions and species compositions on a continental or planetary scale. While small scale, site specific species threatening activities are particularly responded to by the Resource Rarity factor and the Land Degradation Index systems, these components do not respond to global habitat alterations. If a species simply relocates rather than being reduced, there is no corresponding flux in EcoCost. The question then needs to be asked if climatic change (leading to habitat change) is in fact ecologically degrading? Is this a shortfall of the system or one of its findings? An added complexity arises with the identification of isolated alpine ecosystems which cannot relocate and simply dissapear out the top of the habitat range as temperatures rise causing species extinctions.

Change is the natural state of any viable system, including ecosystems. Static systems must by their nature eventually become redundant as all around them changes. The functioning of the universe, as we currently understand it, dictates change through the underlying principles of entropy and enthalpy and the concept of a linear flow of time.

While change is seen as the antithesis of stable society by our civilisation, it may be simply an aspect of existence, one that we must come to terms with in order to attain sustainability.

The pace of change is the crucial part of the concept. Gradual change which allows native ecosystems to adapt and maintain their viability has little detrimental effect to ecosystem and may even be a necessary part of their continued evolution and even existence. Extremes of rapidity in change brought about by human intervention must however have a detrimental impact. Rapid change will not allow the relocation of threatened species forms or the evolution of native biota to cope with that change. Rapid changes in habitat conditions combined with the prevalence of highly mobile and adaptable exotic species (vegetation, insects and animals all included) can lead to the rapid decimation of native and endemic ecologies.

Further investigation of these concepts is necessary.

6.0 Concluding Statements

In conclusion, it is appropriate to take the principal aims of the thesis as expressed in the Introduction section, 'The Purpose of EcoCost' and detail the way in which these have been addressed by the EcoCost analysis.

The principal aims of the EcoCost Thesis were:

- *to investigate the concept of an ecological cost of material procurement;*

The EcoCost system has demonstrated the gap between the current economic paradigm's determination of the cost or value of an object or product and the cost in ecological and sustainable resource terms of procuring that object or product. There is no obvious correlation between the economic monetary cost of an item and its EcoCost. The manner in which so many environmental and social costs are externalised by the current economic rationalist paradigm reflects a major malaise in our culture. 'Internalising' these 'externalities' is critical to achieving sustainability in our civilisation (*Jacobs, 94*).

By investigating the concept of ecological impact in the context of the current scientific, philosophical and idealogical stance of our culture, a series of parameters of ecological impact were identified which could be used to inform the development of the EcoCost system. By focusing on biological factors and excluding anthrocentric parameters, a clearer picture of the infracting causes of ecological impact was achieved. The particular focus on biomass and biodiversity as the factors of ecological health of an ecosystem allowed for the identification of an empirically verifyable series of criteria for determining ecological well being and from there, ecological impact.

- *to analyse, critique and assess current methods of assessing the environmental impact of the consumption of materials;*

The thesis produced an overview and critique of current environmental impact evaluation systems and used the critique and shortcomings of these systems to inform the choices of EcoCost parameters. The range of systems currently available fall well short of a thorough, objective, quantitative, comparative ecological evaluation. The subjective analysis required for most of these systems puts them deeply into the anthrocentric category and removes them from the reality of the health of the ecosystems they seek to assess.

None of the systems critiqued addressed the issues of the direct impact and effect of humanity's activities on biomass and biodiversity. No relation was made to any consistent reference frame by the systems critiqued, this prevents any of the systems from being inter-related or used comparatively. Most of the systems critiqued had been set up as commercially marketable tools rather than as scientifically based measuring devices and publically available advice systems.

None of the systems attempted an overall quantified comparative evaluation. Broad based quantitative ecological evaluations are the optimum way within our current sociopolitical system of allowing valid comparisons between alternatives and new system must be developed to provide this necessary information and advice.

- *to develop a biologically rather than anthrocentrically focused approach to the assessment of ecological impact;*

By assessing ecological impact entirely in terms of ecological indicators the EcoCost system achieves at least a good beginning at a biocentric evaluation system. Focussing on the ecological principles of biomass and biodiversity as a beginning point, rather than any anthrocentric environmental analysis of romantic notions of wilderness value or visual integrity was beneficial in directing and disciplining the EcoCost system. Throughout the EcoCost algorithmic development existing anthrocentric value judgements and subjective analysis were identified, examined and avoided. Grey areas still exist in the determination of land degradation indexes, capital impact, amortisation, greenhouse effects, and other peripheral areas. These require further investigation, more empirical research data and a wide agreement on the status of qualitative issues in the decision making process, to resolve.

It is important to remember that the EcoCost system is seen as simply one phase in the environmental impact analysis of humanity's actions. There are numerous extant social and economic consequence advice systems currently employed in resource decision making. It is critical that these now be offset by an empirically verifyable, ecologically based evaluation tool. A further step required by decision makers now may be to develop weighting systems for anthrocentric value parameters to be weighed against ecological costings.

The dramatic piercing of the anthrocentric veil has been part of the contribution of the modern scientific revolution and the philosophy of deep ecology to our culture. Once recognised this veil may be analysed in a self aware manner and its value to the decision making process clarified and seperated from the objective non-anthrocentric analysis of the results of our actions.

- *to reduce the amount of unacknowledged subjective analysis in the evaluation of ecological impacts;*

Where-ever possible within the constraints of current understanding and data, the EcoCost system has eliminated the requirement for subjective analysis. The system has been based on the contemporary principles of scientific falsifyability and empirical verification, that the results given and predictions made from those results must be experimentally testable. This requires an reified link between the parameters employed for evaluation analysis and the reality of the planetary ecosystem.

With the current insufficiency of empirically derived data some subjective analysis has been utilised in the example EcoCost workthroughs given here, this has been clearly recognised and emphasised. Eliminating these subjective analysis is a high priority for further research.

- *to develop a robust framework which will facilitate the application of extant available information databases and impact indexes to the ecological cost evaluation algorithms;*

The methodology employed in the development of the EcoCost system was expressly chosen to allow the problem to be broken into its constituent parts. This allowed each of these parts to be addressed within the constraints of currently available data and understanding. In each parameter analysis a consistent base reference frame (the planetary ecosphere) was employed together with a scalar or proportional analysis of the degree of impact in comparison to a no impact situation and a maximum impact or total ecological degradation scenario. These two reference frames remain epistemologically valid regardless of the form of assessment of the actual on-ground ecological impact.

The final stage of understanding the interactions of these individual parameters and developing that understanding into an ecological impact evaluation algorithm thus became removed from the processes of on-ground impact evaluation. By this method a robust framework has been developed which does not depend on particular factors or assessment techniques for its validity and can be applied to the latest understanding of the actions of ecological impact.

- *To work through and compare example materials to verify the workability of the system and gain some indicative insights into the portents of the systems findings.*

Two comparative examples (F14 S.H.W. kiln dried eucalypt cladding from clearfell local source and corrugated steel cladding sheet sourced through the IronBack Range, Whyalla refinery and Newcastle rolling mills) were worked through with provisional data and deduced indicative findings from these examples detailed. The examples have demonstrated the workability of the system and the value of even preliminary findings in providing useful advice for decision making. The detailed workthorugh of these examples and the information bases required for the system are shown in Appendix Four on Example Workthrough.

The findings detailed in the Principal Findings Section demonstrate the critical necessity for the instigation of EcoCost type systems of evalution. They show that a number of the practices currently undertaken under the banner of environmental responsibility may well have a major detrimental impact on ecosystems, far beyond the current mainstream perceptions. The comparative quantitative analysis of issues allowed by the EcoCost system highlights that the core causes of ecological degradation are not being addressed in any meaningful way by current decision making.

Many areas of extreme global ecological impact, particularly freight transport and personalised internal combustion engined vehicles, are treated in a very superficial manner by contemporary cost benefit analysis. The comparative analysis provided by the EcoCost system determines that personal transport of humans has an effect an order of magnitude more damaging than road freight, which in turn is an order of magnitude worse than than rail, which in its turn is two orders of magnitude worse than sea freight. This has never been recognised properly in resource allocation decision making at a national government or authority level. Even through preliminary indicative analysis of this sort EcoCost illuminates the critical need for its proposed form of evaluation to be integrated in decision making systems as a matter of priority.

6.1 The Inevitable Call for a Paradigm Change

Our current economic system is incapable in its present state of representing a non-anthrocentric ecological impact evaluation of the cost of the actions of humanity to the global ecosystem. We rate the value/cost of things from an entirely anthrocentric viewpoint of the human effort that has gone into the creation of an article or product, completely ignoring any side effects or resource limitations.

For our society, up till now, the future has been someone else's problem, this is now beginning to change. The principal issue of the future is sustainability. Sustainability requires that our actions must have no detrimental effect on the future, not just the future of humanity but of the entire global ecosystem. Some economic theorists talk of avoiding a reduction in environmental capital. To this end we must understand the full ecological implications and repercussions of our actions to allow valid decision making.

Whatever the decision making process, the requirement is always for reliable information and advice to allow one choice to be weighed against another. The EcoCost system is deliberately limited to the single aspect of the decision making agenda that deals with the impacts on the environment, more specifically on ecosystems, of the procurement of building materials. It can be broadened to be used as an evaluation system for any physical process without structural change. It is deliberately designed to fit within the existing environmental impact assessment processes of the current technologist-economic-rationalist institutions. It is a 'straight' system which determines a comparable numerical rating for a product to allow it to be compared to all the others on the market in terms of its ecological appropriateness.

7.0 The End

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1575 of the Worlds Leading Scientists

30 Years to Save the Planet !

Union of Concerned Scientists 1990

A broadsheet detailing the warning given to the worlds population of humans by 1575 of the worlds most senior and eminent scientists that the earth will be unable to sustain plant and animal life unless humans end their threat to the environment.

Dire warnings backed up by deep statements of the state of the earth and the projected effects of humanity's habitation and actions.

ABARE

Agriculture & Resources Quarterly, Volume 4, No 2,

ABARE June 1992

Quarterly updated, wide ranging resource procurement statistics collection giving quantities and location of sources for minerals and agricultural products: ie steel, aluminium, sheep's wool, sand mining etc Excellent statistical information base and initial source guide.

American Institute of Architects

Environmental Resource Guide

American Institute of Architects 1994

Sustainable and Healthy design information. Environmental assessments, life cycle analysis, maintenance information, etc., on various building materials.

Updated Quarterly, available from
The American Institute of Architects
1735 New York Avenue NW
Washing DC20006, U.S.A.
(US) $200.00 + $8.00 shipping

ANZAScA. Dr Graham Holland and Mr Ian Holland

The Technology of Design Conference Proceedings

ANZAScA July 1991

A statistical argument for promoting the Use of Radiata Pine Plantation Timbers followed by some very dubious and incomplete biological and environmental arguments. Reveals the potential volumes of softwood about to deluge the market from 1995 onwards from NZ and Chile. Reaches some very good conclusions which have nothing to do with either Radiata Pine Plantations or with the foregoing arguments. Cites numerous interesting references.

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Still only in prototype stage but a good database nevertheless, especially in cases where wider parameter research has been carried through. Will be very useful for land degradation index analysis once complete and on-line.

Babbie, Earl

The Practice of Social Research (fifth Ed.)

Wadsworth Publishing Company 1973

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Then goes on to show the importance of sampling techniques and representativeness of sample. Chapter 13 deals with collating and computerising results of questionnaires and surveys. Other less useful chapters deal with analysis, statistics and modelling methods.

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Proposes strategies for amelioration of ecologically degrading land management practices.

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Hodder & Stoughton , Sydney 1990

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Towards a New System of Environmental Governance

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Coghill, Ian

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Sorett Publishing, Melbourne

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National Parks and Wildlife Service. Tas. May 1986,

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Based on land area in the surveyed site, species density, species representation, site pristineness, ecosystem type and representativeness.

E.S.D. Steering Committee

Compendium of Ecologically Sustainable Development Reccomendations

Aust. Govt. Pub. Serv., Canberra 1992

Accompanying volume to the National Strategy for ESD giving summarised listings of strategies for the various areas analysed including, Forestry, Mining, Agriculture,Health and Medicine, Engineering, Manufacturing, Fisheries,Energy,Tourism,Transport, Trade

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National Strategy for Ecologically sustainable Development

Australian Government Publishing Service, Canberra 1992

A series of strategies developed through wide community, Industry, professional and academic consultation by the steering committee for implentation by the government and developers to encourage sustainable development in ecological, social and economic terms, for the various areas analysed including, Forestry, Mining, Agriculture,Health and Medicine, Engineering, Manufacturing, Fisheries,Energy,Tourism,Transport, Trade.
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MTP Construction U.K. 1974

Source for analysis of properties of Building Materials, Longevity, durability, strength, applications and technologies.

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Environmental Protection Agency USA 1972 -1978

Source for air pollution data for industrial processes. Highly detailed information about quantities of pollutants emitted by various industrial processes. Mostly out of date - new information must be available somewhere but is not open file. Wide ranging analysis of air pollution from industrial processes using point source measurements: part of the U.S.A., E.P.A.'s continuous monitoring program. Easily available up to the early 1980's very hard to find from then on.

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Technical Medical Text on the toxic effects of particular substances, ie lesions from SO2, necrosis from acid precipitation, reduced availability of soil nutrients through pH changes, Ozone depletion by CFC's,

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Flannery, Tim

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Analysis of Australia's ecosystems ability to support human populations, from a continental, geological and climatic perspective. Develops figures of 6 to 12 million people as the optimum human population from a sustainable biological standpoint and "probably towards the lower end of that range.

Fox, Avril & Murrel, Robin

Green Design: a guide to the environmental impact of building materials

Shallow assessment of various building materials from a non-quantitative, non-scientific, hear-say viewpoint. Some useful but non-corroborated information on toxic materials and sick building syndrome. Wide range of materials covered.
Very good introduction philosophy, low on content in body of text.

Appendix 1

Glossary

of terms used in the EcoCost thesis
and in contemporary environmental debate

Andropocentric Androcentric

Definition

Centred about the male of the species Homo Sapiens Sapiens.
Usually of the Caucasian Race.

Usage

Used to describe the dominant Western Paradigm of the latter part of the second millennium A.D. The white Caucasian male is viewed as the controlling force of the culture.
To the detriment of other humans and life forms.

Anthropocentric Anthrocentric

Definition

Philosophy of Humans as the centre of all.

From Descartes "I think therefore I am."

Usage

The term is used to describe the traditional human centred philosophy where the universe is seen as being here for the benefit of mankind and for no other more intrinsic reason.

Attractor (Strange Attractor)

Definition

A point in or state of a complex system which conditions tend towards. May be stationary or moving predictably or moving unpredictably (strange) when mapped.

Usage

Catchword for chaos theory exponents. Describes the idea of unpredictable predictability or the ability to see patterns in very complex behaviours.

BioDiversity

Definition

Bio ; Organic life
Diversity ; Range, variation.
Hence, the range or variety of organic life.

Usage

Currently used as a measure of the naturalness, health or vitality of an ecosystem. Theory suggests an optimum niche diversity which when fulfilled gives the most natural scenario.

BioMass

Definition

Bio ; Organic Life
Mass ; Quantity of matter
Hence, the quantity of organic life.

Usage

The biomass concept explicitly states that the planet earth is capable of supporting a given finite mass of organic life. The figure depends principally of the incident energy available from the Sun on the planets surface.

Biota

Definition

A descriptor for all living organic matter.

Usage

Used as a term to include all living matter in a given zone.

Chaos

Definition

A mathematic term used to describe the behaviour of complex systems, whether predictable or not.

Usage

Chaos theory describes the idea that certain complex systems can be modelled by simple mathematical functions and demonstrate a repetition of patterns at different scales of observation.

Complex Systems

Definition

Any system which exhibits complex and seemingly unpredictable and unexpected behaviour. Includes such natural systems as ecologies, the weather, the human brain and others ,ie economics.

Usage

Used in mathematical analysis of chaos theory and non-linear modelling to represent, analyse and attempt to predict natural and man made phenomena.

Deep Ecology

Definition

Philosophy presenting the idea that man is not the centre of all but a part of an complex interactive ecosystem. A biocentric view that all living things have equal status, rights and responsibilities.

Usage

Widely used to describe the thoughts of philosophers on the radical fringe of the environmental movement.

EcoCost

Definition

An ecological evaluation system for building materials.
based on available information dealing with toxic impact, land degration, energy consumption, transport, longevity, recyclability

Usage

A catchword for an ecologically based evaluation system developed for use by designers, architects, builders and material specifiers in the construction industry.

Ecofeminism

Definition

A philosophical and political movement highlighting the link between androcentrism and environmental destruction.

Usage

Ecofeminism is a value system, a social movement and a practice. It is about changing from a morality based on "power over" to one of "power to", away from macho displays and towards understanding.

Ecology

Definition

The relationship of living organisms to each other and their surroundings (environment)

Usage

Term denoting the totality of complex biological systems and interactions. Non-anthropocentric view of the planetary biological systems and interactions (including humans as animals).

Ecosystem

Definition

A particular set of Niches or habitats and their associated life forms that interrelate to form a linked biological entity.
An interactive ecological system.

Usage

Used in various levels of ecological analysis from the microscopic through to the global to describe the whole of the ecological system with all its complexities and interrelations.

Ecotype

Definition

A particular, recognisably different form of a species resultant from slight variations in the Niche parameters.

Usage

Used in biological assessments to denote a particular case exhibiting important departures from the norm of a species due to particular endemic environmental influences.

Endemic

Definition

Of the place and only of the particular place.
Natural to and found only in the place in question.
Related to a particular localised habitat and niche.

Usage

Used to denote the belongingness of a species, ecotype or object to a particular place. Something which has evolved to fit into the ecosystem (environment) of a place.

Energy Audit

Definition

A technique to thoroughly analyse the energy input into the given process, including all subsidiary inputs and capital input.

Usage

Used as a crude approximate ecological impact evaluation system.

Environment

Definition

That which surrounds.
Conditions of Existence

Usage

Widely used to denote the entirety of biological interactions.
Often linked to an anthropocentric viewpoint and interpreted as the world surrounding humanity including politics and economics.

Food Chain

Definition

The sequential system of eat and be eaten in an ecosystem.
An analysis of what eats what. Predator - Prey relationships

Usage

The concept of the linkages by consumption in an ecosystem.
Also traces the movement of toxins between affected species and those affected indirectly by consuming those directly affected.

Genus

Definition

A group of species of like genetic strains, usually capable of interbreeding but of distincly different appearance. Will not reproduce true to type from a cross breed.

Usage

A descriptor of recognisable groups of life forms.
See Species, Genera, Family, Order, Phylum, Kingdom.

Habitat

Definition

The physical or descriptive place in the ecosystem occupied by a particular species of organic life. Also in the broader sense, the general conditions required for a particular ecosystem.

Usage

Used to describe either a particular place or a generic type of place where a particular species / ecosystem should or may be found.

Incident Energy

Definition

Transmitted energy arriving at a point.
Available continuous energy supply

Usage

Used to identify a level of energy available on the planets surface from solar radiation. The principal governing factor of potential Biomass capacity.

Index

Definition

A numerical evaluation of a parameter.
A system of analysis to give a comparative numerical assessment or weighting of a given factor.

Usage

Used in ecological evaluation and analysis systems to allow comparative analysis of ecosystems and various parameters affecting them.

Land Degradation

Definition

The reduction in the potential of a site to support ecosystems due to damage to the surface of the land.

Usage

A major parameter of human impact on the ecology. The direct impact of material procurement processes on the ability of the land to support viable endemic ecologies.

Natural State

Definition

The optimum viable state of a complex ecological system affected only by endemic parameters.
Final succession state of an ecosystem.

Usage

Used to denote the unaffected prehuman state of an ecosystem. Especially useful as a benchmark and reference state for determining ecological impact.

Niche

Definition

A particular set of ecological parameters which are required for the growth of a particular species of organic life.

Usage

The niche concept is used in biological assays to determine which species should be or are most likely to be present for a particular ecological situation. see niche width and niche volume.

Niche Volume

Definition

The number of specimens which may be supported in the given niche.

Usage

Gives an idea of the size of the niche and the proportion of the Biomass potential it may assume.

Niche Width

Definition

The range in the ecological parameters for which the niche is still valid.

Usage

Used to give an idea of the strength or adaptiveness of the species (sometimes also used to denote the flexibility of the ecosystem to withstand changes in conditions).

Non-Linear Modelling

Definition

Mathematical term describing the representation of systems which seem unpredictable and/or which have no obvious guiding pattern or algorithm or which follow an unpredicable path.

Usage

Used in chaos theory to develop models and mappings of complex systems in order to develop predictions of their behavior or determine patterns.

Parameter

Definition

A variable factor affecting the thing for which it is a parameter of.
or a constituent element of the thing for which it is a parameter of.

Usage

Used to examine the variation of a given particular part of a greater whole and to allow dissection and analysis of it's behaviour.

Pollution

Definition

Solid, liquid or gaseous discharge into the environment to the detriment of that environment. Often linked to humanity's activities especially in industrial process outputs.

Usage

Commonly used to describe any substance which is detrimental to ecosystems produced by humanity's activities.
See toxicity, toxins.

Post Impact State

Definition

Condition of an Ecosystem after the impact of an inflicting process has taken effect.

Usage

Useful in determining the ecological impact.

ie; Natural State Index - Post Impact State Index = Ecological Impact Index

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Post-consumer Pre-consumer

Definition

Indicates before (pre-consumer) or after (post-consumer) use.

Usage

A term describing the state of material prior to recycling processes. Often used to confuse issues of recycling and reusing.
Recycled pre-consumer is just as wasteful as new.

Recyclable

Definition

Capable of being recycled. Made of materials which may used as raw materials in other procurement processes.

Usage

Often used to confuse issues of recycling, recyclable is NOT recycled.

Recycled

Definition

Made of material that has been pre-used in some other form and then utilised as a raw material resource for a further industrial process.

Usage

A material that has been reprocessed or remade. Indicates the presence of a developed system for the collection collation and processing of used materials into new materials.

Renewable

Definition

Capable of replenishment without deteriorating a capital resource.

Usage

Used to describe resources which naturally regenerate or may be replenished without deteriorating a capital resource. eg; Solar energy, biological products (timber, vegetable and animal oils, etc)

Reusable

Definition

Capable of being reused in its current state after the initial use has expired.

Usage

Applied to materials which can be re-employed without further industrial processing or remaking.

Species

Definition

A group of organisms capable of interbreeding and reproducing true to type.

Usage

Used to describe a particular recognisably distinct life form.
The basic principle of taxonomic organisation.

Species, Genus, Family, Order, Phylum, Kingdom.

Definition

Ascending scale of biological inter-relation.

Usage

Used in biological analysis, taxonomy and nomenclature of living organisms.

Sustainable

Definition

Supportable, Maintainable, Succourable, Back-upable
Capable of continuous renewing.
Valid, sound, correct, true or just. Temporally viable.

Usage

Used to denote processes which are capable of continual renewal without any detrimental ecological effects. Widely used with varied interpretations in the arena of green and anti-green politics.

Sustainable Development

Definition

Development that follows sustainable principle or methods to achgieve its other goals.

Usage

A coverall term used widely to describe environmentally benign construction, resource procurement and other development.
Often misused and misinterpreted term.

T.T.O. Total Toxic Overload

Definition

The concept of permeation of the food chain with toxins entering at all levels and concentrating towards the top.

Usage

Describes a point at which the food chain becomes so loaded with toxins it can no longer cleanse itself and, due to the compounding of effects moving up through the chain, collapses.

Temporal

Definition

To do with time.
Of a certain time.
Related to time.

Usage

Used to denote and express that time is a principal parameter of the condition being described.

Toxicity

Definition

An assessment of the damage potential of a substance in biological and/or ecological terms.

Poison rating of a substance.

Usage

Used as a measure to describe the impact of pollutants on ecosystems. Deals with potency, method and duration of effect.

Toxin

Definition

A particular substance which is detrimental to an ecosystem.
A poison

Usage

Used to describe a particular chemical or pollutant .

Wilderness

Definition

Wild or uncultivated land. Uninhabited by humans
Desolate, place of loneliness, lost.
Place free from the effect of human interaction

Usage

Seen by some as a place unsullied by the activities of humanity, by others as a useless, threatening wasteland awaiting exploitation and taming in the interests of humanity.

Appendix 2

Potentialities

Ideas and thoughts developed during the course of the EcoCost Research which may provide avenues for future research into improved ecological evaluation systems

Potentialities - Some Loose Ends

The Eco Cost Budget

The notion of an EcoCost Budget touched on in the thesis is one worthy of development as part of this work. An EcoCost Budget, when properly set up, would allow the designer to obtain an appreciation of how much resource should be expended on the particular structure or place, in terms of its social, cultural or contextual importance. This would allow an optimisation of resources through a cost-benefit analysis. How the budget would be determined is a matter for much wider conjecture, whether community priority, commercial gain potential or socioeconomic priority is used for resource allocation decision making. Assuming that such decisions can be made either at community or personal level, the designer would have an allocation of EcoCost within which material and design choices may be made in the usual contemporary manner.

A corollary of this would be that architects should be able to budget, in an ecological sense, for the use of some highly desirable but perhaps ecologically costly material in some part of a structure/place in a trade off with using some very low EcoCost materials in other areas to keep within the overall ecological expenditure allowance for the project. This is simply a realignment of the current economic budgeting patterns. The EcoCost system could thus make use of existing highly developed financial optimisation systems to maximise benefits while minimising ecological impact. A desirable goal.

Within the EcoCost Budget, as with the EcoCosting of materials, an allowance would be made for the longevity and robustness of the structure. The longer a structure serves a useful purpose the greater the amount of initial resource expenditure can be justified, or alternatively the more the initial EcoCost may be amortised. An assessment should be made with reference to the same parameters as the EcoCost as to the expected life of the building/structure/place. The EcoCost should be spread over the usable life of the structure allowing a greater EcoCost to be justified by a much increased life and conversely demonstrating that the EcoCost rises rapidly with short lived non-recyclable structures.

The idea of EcoCost budgeting is one that can be employed by the concerned designer without relevance to the official bureaucracies adoption of such a system. It has little or no reference to the operating economic system although it does tend to seem comparable to the casual observation. This allows it to be taken up within the current technologist-rationalist culture without direct confrontation.

The principal parameters for the determination of an EcoCost Budget could be;

i) Role of building/structure/place

ii) Longevity

iii) Usage

iv) Robustness, ie, ability to be reemployed.

v) Social, philosophical and architectural significance.

Who determines the EcoCost Budget would be an issue of great importance to its success. Such issues are linked to the power and control systems extant in the community. The more local the decision making authorities base, the less global you could expect the result to be, the more global the authority, the less local the result. Herein lies an entire field of decision making and social control philosophies, which lies outside the confines of this thesis. (*Jacobs, 1991; Birkeland, 1993; Plumwood, 1993*)

Complex Systems Analysis of the State of the Environment -
Beyond EcoCost

The next step beyond the proposed EcoCost system given in the preceding text may utilise the emerging sciences of complexity and non-linear systems analysis. There are two approaches to the problem from the complex systems angle. Both involve making multidimensional 'maps' or as the jargon goes 'State Space Surfaces' which are, in this instance, in effect models of either the state of the environment or the effect on the environment of impacting processes. To apply these sorts of analysis to the EcoCost system will require either the resolution of a descriptive formula for the state space surface or the empirically determined mapping of the surface. In either case the development of mathematical methods of locating starting surfaces, points and impact vectors and volumes will be essential.

The EcoCost system suggests ecological impact evaluation shows an extreme sensitivity to initial conditions and a strong relationship to impact location in time as well as space, both of these are features of complex non-linear systems state space mappings which suggests a relevance in this approach.

The state space surface mapping of the ecological impact of material procurement processes will require identification of all major impacting variables. This would, in effect, be a multidimensional graphing of the EcoCost Parameters. The more accurate the approximations in the parameter evaluations in the EcoCost system, the closer the mapping would resemble an empirical, absolute surface. This multi dimensioned surface would be a usable mapping of ecological impact. By determining the initial pre-impact conditions and then summing the impact vectors of individual evaluations of the various ecological impact parameters, a resulting vector representing a quantification of ecological impact could be determined.

Alternatively, the currently available information on indicators of the condition of the environment could be used to create a similar multidimensional state space mapping, this time of the 'State of the Environment'. By analysing the broad range of ecological indicators for particular isolated impacts and using their ecological health assessment as a dimension of the state space, a surface may be mapped. This mapping would not require an analysis of the effects of various parameters of impact, being essentially empirically derived. Alterations in this state space surface due to human actions would coincide with environmental impacts. Mathematical analysis by integration could find the volume of the space between the original unaltered state space surface and the impacted state space surface and this could be interpreted to give an accurate, real, quantitative measurement of environmental impact.

A computerised state space surface generated in either case could be put on line with the information databases to maintain a real time, up to date mapping.

This system would have two advantages;

- firstly it could use the information bases currently being developed throughout the world by various environmental agencies. In the empirically derived state of the environment case the data would be used directly without requiring interpretation or analysis, eliminating another area of assumptions. State space mapping of empirically derived data would alleviate the need for the approximations involved in the use of a single algorithm linking the parameters and the potential for contention this entails.
- secondly there would be no requirement for an interpolation of the final result, the result given would be an actual numerically translatable quantitative assessment of the full environmental impact of the particular action.

By analysing the forms of either of these environmental impact state space surfaces, particular commonly resulting states which ecosystems would tend towards under the impacts of humanity, or as the jargon puts it, 'attractors', may be identified. These would indicate either stable environmental states or ecological peril regions. The principal attractor would be the natural, prehuman state of the environment, as this is the state the system would tend toward without human intervention. An alternative attractor related to the uncurtailed activities of humanity, would be located at the point of the 'Total Toxic Overload' of recent myth. At this point toxic effects rapidly become magnified through food chains due to the systems inability to purge toxic buildups. This leads rapidly to a state where the whole system reaches lethal toxic levels and collapses.

Intuitive analysis would suggest various other facets of the state space surface, it would display the following features:

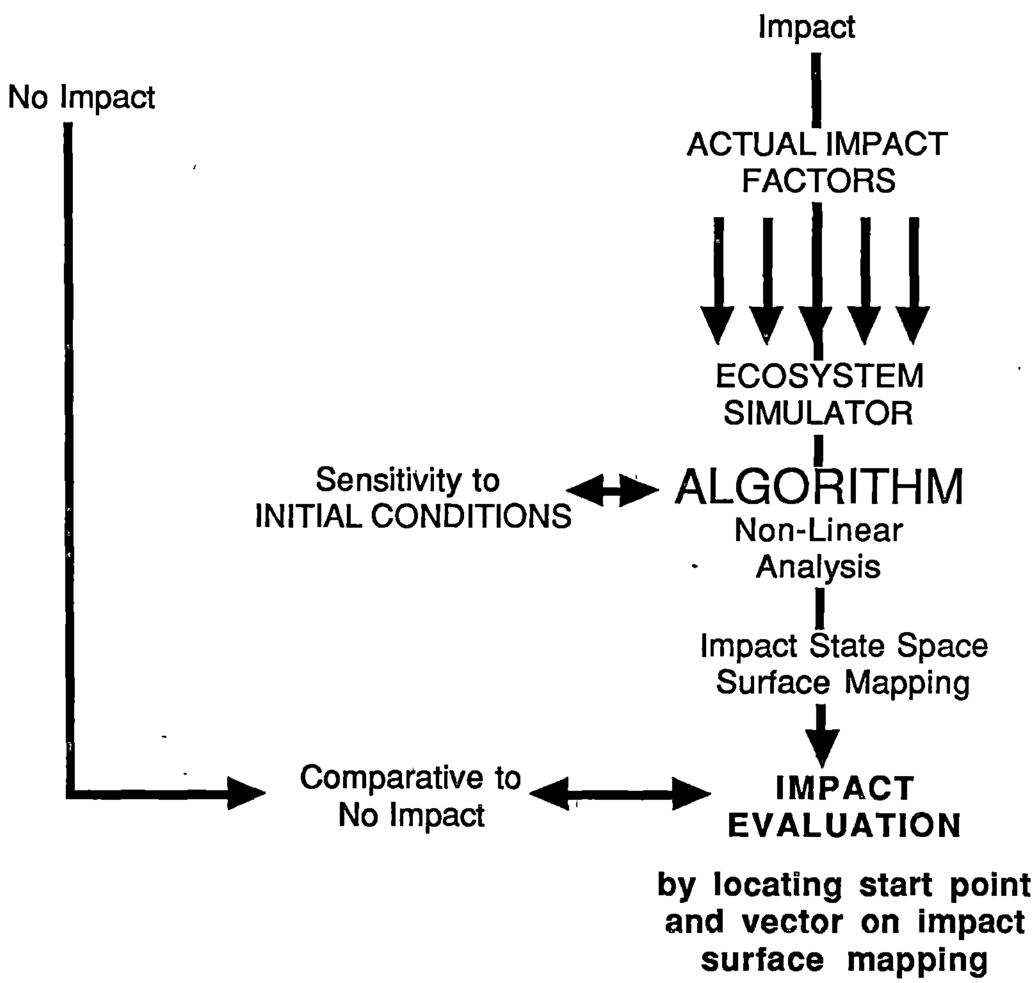
- decrease in dispersal capacity with decrease in pre impact state;
- increase in impact with decrease in pre impact state;
- increase in impact with increase in toxic output quantity and toxicity;
- decrease in pre impact state with lower natural state;
- decrease in pre impact state with increase in duration of impact (given discrete analysis);
- decrease in pre impact state with lower dispersal capacity;

These intuitive analyses suggest the impact state space surface may be imagined as a peak signifying the area of maximum degradation of the ecosystem sloping away asymmetrically and in some areas exponentially according to the impact being caused by human activities. The peak will be in the region of low pre impact impact state, low dispersal capacity, high toxic output quantity and high toxicity, the antithesis of the natural state.

Conversely the state space mapping of the state of the environment would be best imagined as a rounded hill representing the natural unimpacted state surrounded by a ring of pits representing the various collapse of the environment possibilities resulting from human activities, (over consumption, compounding species extinction, habitat decimation, monoculture crop failure, ozone depletion, greenhouse effect, total toxic overload, nuclear holocaust, bioengineering or genetic manipulation disaster and so on)

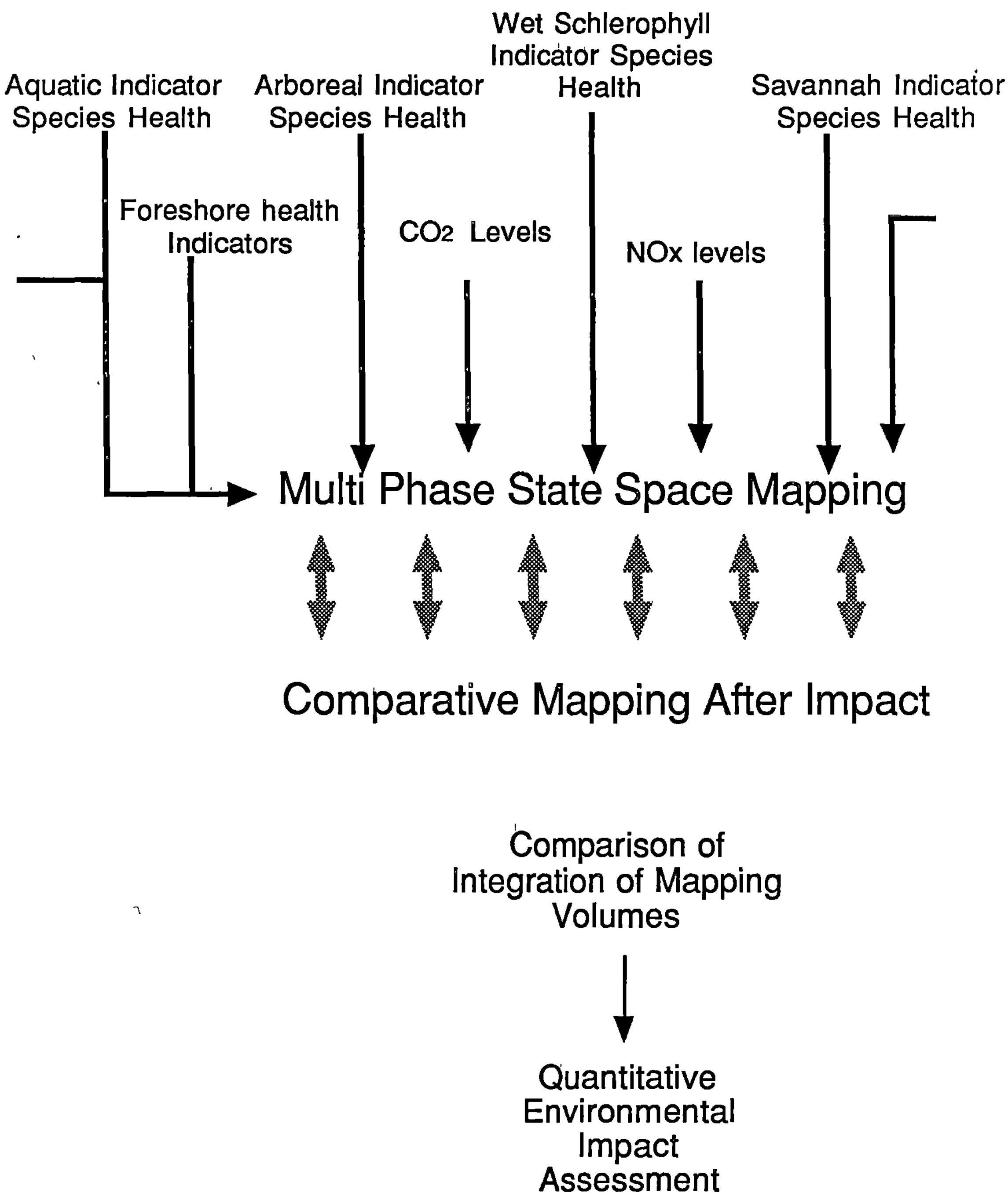
Some two hundred and forty odd criteria are currently used by the N.S.W. E.P.A. to determine a 'State of the Environment' analysis. Little attempt is made to inter-relate these parameters and hence there is little information made from the data. A state space mapping would allow an overall 'picture' of the state of the environment to be made and would enable deeper perceptual understanding of the effect of impacting actions on the ecosystem. A state space mapping would make information out of the data and allow advice to be generated from the interpretation of that information. Comparative analysis of the changes in the state space surface over time could give a usable assessment for resource allocation decision making of the performance of the society in reducing its impact on the environment.

Complex Systems Analysis Methodology



State of the Environment State Space Mapping

NOTE: Some 454 indicators are proposed by the N.S.W. E.P.A. for State of the Environment Analysis



Computer Applications

Both the proposed EcoCost system and complex systems analysis state space modelling are eminently suited to the application of computing and information transfer technology. The stated requirement of sheltering the user from the more complex and daunting of the algorithm's functions is served ideally by the user friendly nature of contemporary, and future, computer technology. The manner in which networks are taking over the world's isolated information technology systems allows for rapid transfer of huge volumes of information without any requirement for input from the user. This rapidly changing, relevant data stream could be continuously interpolated by a computer to give topical advice on material selection. Centralised, on line, continually updating systems could be set up to allow network access by remote users to major environmental assessment software and databases. These systems are particularly applicable to the use of complex systems modelling and analysis.

Alternatively stand alone user interactive information packets could be developed for isolated users.

A large part of the future of Information Technology will be the provision of advice systems for network access. The development of 'Expert' systems (and the emerging 'Agent' software) to give EcoCost analysis and advice on the most appropriate materials for particular applications fits neatly into this scenario. Sub-routines to hunt out relevant data and new research findings through keyword searching and artificial intelligence Agent browsing could be used to constantly monitor research developments and even upgrade the system, particularly with regard to other itinerate factors for the Itinerate Impacts Factor. With proper development of the concepts of cyberspace, it can provide access to valuable relevant contemporary advice for a broad range of users and could have a profound effect in reducing the impact of our species on this planet.

Some Political Observations

One of the largest obstacles in the way of a radical alteration in the manner in which building materials are chosen and construction systems applied is the current government standard requirements and the associated public service unions' workplace standards for building tenancies. The requirements for air conditioning, artificial lighting, temperature, surface finish, floor area specifications and fire hazard specifications, all dictate the use of environmentally and ecologically unsound materials and practices. The reasons for the stringent and pedantic nature of these requirements are spurious, in many cases they lead to a lessening of wellbeing for the buildings occupants. In all cases they result in a total elimination of control over personalised environmental conditions for the occupants.

The manner in which brief setting is carried out by unaware bureaucracies is an issue of major concern. This major force in shaping architecture, and creating environmental impact at one remove largely goes unnoticed or at least uncommented on. The workplace condition requirements together with the economic limitations for any building to be acceptable to the major public service unions and federal government building management sections leads inexorably to a particular dominant pattern of building type. In the contemporary model these buildings tend to large, energy hungry, heavily over serviced, heavy consuming, formidable structures which are uncontrollable on a personal user level. They are also highly likely to suffer from indoor air pollution as a result of a combination of their closed nature and the materials commonly specified for their lining out, furnishings, finishes and surface effects. Solvent based paint systems, composite materials using formaldehyde based binding agents, resin based sealers and other compounds all add to the build up of indoor air toxins.

By altering the leasing requirements issued by the government building procurement authorities to reflect wider government policy and priorities of environmental and ecological responsibility, major gains could be made towards achieving sustainability in building practice in this country. It would seem that utilising this avenue of control, government policy on sustainable development, in as much as it applies to the built environment, could be enacted rapidly and thoroughly with a minimum of legislative intervention.

A Fashion Statement.

Fashion in design can be a much stronger influence than philosophical or social imperatives, let alone environmental or ecological issues. Fashion relates to the topical, to the 'trend' of the moment. In our era of near instantaneous global information transmission the topical changes daily, even hourly. What then does fashion do? The encouragement of an underlying sense of necessity for environmental awareness should lead to a valid sustainable starting position from which fashion could develop. It is mooted that the EcoCost system be developed as a pre-design information and advice tool. Thus the principles required for ecologically sustainable architecture would be instilled into all designs prior to the application of formal fashion pastiche. All buildings regardless of function, form, style or imagery should be environmentally responsible in the same way that they should stand up. It is a prerequisite not a stylistic option or fashion accessory.

Green Economics in Building Costs.

There is one aspect of building that over-rides even fashion and that is economics. If the economic system can be made to take into account ecological impact evaluations then these will be directly reflected in the costing for given building materials, types and forms. Thus the more environmentally damaging a building, the higher will be its cost. This will have a profound effect on building design.

Green economic principles are now influencing national and international economic policy. The principal focus and tool of economic policy is the monetary system. The anomaly of our monetary system, based as it is on confidence in the continuation of the system, is that it is not intrinsically linked to any fixed reality. As such it is a simple matter to link it to one. The floating of the Australian dollar from a fixed assset representation last decade had little appreciable effect on the operations of day to day life. To now anchor the monetary system to the sustainable resource income available on the planet would have a similarly limited initial effect. In this proposal an ecologically based evaluation system is suggested as a replacement base for the monetary system.

The more refined principles of economics defy intellectual comprehension but the contemporary monetary system should be able to be adapted to work with such an ecological base. Such a grounding of the current volatile monetary system addresses the imminent problems emerging from the concept of the requirement of unlimited growth for the maintenance of healthy economies. Linking the global economic system to the reality of the planet would demonstrate the limitations of the world and underscore the inherent requirements for sustainability. Resources are limited, they are finite, only so much energy is available, there is only so much area to occupy for human habitation, food and resource production and the rest of the global ecology to exist on. Balancing an economic budget in such a system would be a meaningful act of living within the sustainable resource base of the planet. (*Jacobs, 1991; Birkeland, 1993; United Nations Conference on Environment and Development, 1992;*)

Appendix 3

Land Evaluation Systems

An analysis of available land evaluation systems used for environmental impact evaluation in various locations around the world.

Analysis of Land Evaluation Systems

The following text describes a number of systems which have been used by various organisations around the world in order to achieve some form of quantitative analysis of the status or worth of sites in environmental terms.

Landscape Evaluation

A landscape evaluation system developed in the U.K. for application to resource development decisions uses a two stage analysis. The first stage is a taxonomic analysis of landscape types and the second a comparative aesthetic analysis of quality. A simple randomly assigned point system and subjective analysis to give a numerical rating to landscape types. The labelling of forms conjures the subjective nature of the analysis ranging from:

spectacular	(at 16 to 32 points),
superb	(8 to 16 points),
distinguished	(4 to 8 points),
pleasant	(2 to 4 points),
undistinguished	(1 to 2 points),
unsightly	(0 to 1 points).

The point rating is established by design professionals from photographic image assessment of the sites at two images per square kilometre. This system relies solely on anthrocentric value judgments of visual aesthetic criteria, as such it is nearly worthless as a ecological evaluation tool.

Ecological Evaluation - Nature Conservation Council

A point scoring assignment technique for an ecological evaluation index has been developed by the Nature Conservation Council in the UK. Sites are evaluated with the following table:

High Grade Habitats	Score	Others	Score
Woodland	10	Parkland	8
Scrub	10	Orchard	6
Heath	10	Plantation	6
Unsown Vegetation	10	Improved Grassland	3
Tidal Mudflats	10	Arable	2
Sand Dunes and Sand	10	Development Areas	0
Saltings	10		
Freshwater marsh	10		
Freshwater	10		

Each of these landscape types are then linked with the quantitative assessment score:

Absent or nearly absent	0
Present (but not conspicuous)	1
Numerous (Conspicuous)	2
Abundant	3

To give a score usually between 26 and 190. These scores were divided by 10 and then grouped to form classes of landscape value.

Low	3-6
Medium	7-8
High	9-11
Very high	11+

Areas are analysed in 1.6km square grids and maps made of the evaluation of landscape value. This system, while going further into an analysis of ecosystems, falls well short of looking at the biomass or biodiversity potential of an area. The random application of point scores and lack of empirical analysis of ecosystem health are major failings.

An similar form of ecological evaluation for the Arnhem - Nijmegen region of the Netherlands was carried out by the application of subjective analysis by experts of ecological systems in the region.

Ecological Evaluation Index - Helliwell

Helliwell in the U.K. has developed an ecological evaluation index based on the presence and numbers of indicator species within a given site in comparison to the national or local mean presence: The site is divided into habitat types and each habitat is assessed for ecological importance with the indicator species for that habitat type. The site is then gridded and species counts done and averaged over the habitat type areas.

An example of a count of species on a 105 Ha site in the U.K. revealed the following species counts.

Relative frequency	Presence in 100km2 areas			
Species Value	on site	Regional	National	Conservation
Agrostis tenuis	844	77	2600	30
Lolium perenne	16169	80	3000	70
Quercus petraea	1260	51	1300	197.4
Thelypteris phegopteris	1.3	35	600	83.2
Tilia cordata	2.0	4	150	635.6

A rarity value is calculated using the formula

$$\text{Rarity Value} = \frac{1}{\left(e^{(-0.000676y^2 + 0.1613y - 0.1606)}\right)^{64} \times c}$$

where e = 2.71828

y = % occurrence (in the region or nationally)

c = a constant

Conservation Value is then determined by the formula

$$\text{Conservation Value} = A^{0.36} \times (\text{National Rarity Value} + \text{Regional Rarity value})$$

where A = relative frequency on site

Habitat	Area (Ha)	Relative Conservation Value
Woodland	28	2607
Re-Seeded Pasture	36	518
Permanent Grassland	40	1267
Hedgerows	0.45	481
Stream banks	0.45	816

This system appears to have a good potential for quantitative analysis, though the mathematical justification for the numerical manipulation seems spurious. It could be expanded to include animal, insect and other biota types to give a broader ecological analysis. Altering the focus from a rarity evaluation to a simple quantitative analysis of indictor species would appear a less anthrocentric methodology.

Landscape Quality Assessment

Landscape Quality Assessment, also from the U.K. uses a slightly more refined point scoring system to rate landscapes.

Score for landscape components

Element	Description	Rating
Topography	Flat Land (< 100ft diff.)	2
	Undulating (100-500ft diff)	8
	Hilly (500-1000ft diff)	10
	Mountains (>100ft diff)	10
	Open or Moorland	6
Land	Cultivated Land	2
	Derelict Land	-8
	Parkland	8
	Domestic	2
Scale	Perspective over 4 miles	8
	Up to 2000 ft alt.	10
	> 2000 ft alt	10
Vegetation Density (Tree Cover)	< 2%	2
	2 - 20%	8
	20 - 50 %	10
	> 50 %	6
Buildings	Individual dwellings	0
	Farms	0
	Villages of Traditional Style	6
	Villages not traditional	8
Water	Stream or Small River	2
	Large River or lake	8
	Open Water (>25% cover)	8
Detractors	Minor intrusion	-2
	Small but numerous intrusions	-4
	Large intrusion	-6
	Very Large intrusion	-8
Trespass (distance to built up area)	<1 km	-2
	1 - 2 km	-1
	2 - 3 km	0
	> 3 km	0

Though more technically refined this system still utilises an entirely anthrocentric analysis and subjective assessment of ecological patterns. There is no justification for the numerical ratings given either in absolute or relative terms. Why is *hilly* land 10/2 = 5 times as ecologically valuable as *flat* land ? Little analysis is made of the sites ability to support viable ecosystems or the biodiversity or biomass potential.

Environmental Evaluation System

Developed by the Batelle Laboratories in Ohio USA this system uses a checklist of 78 environmental and socio-economic factors each given a subjectively weighted numerical value scale. Experts assess the given site to determine a rating for each of the parameters as a proportion of the allowable scale.

The system has been used for environmental impact modelling for proposed projects by developing before and after ratings and noting the net change across the range of factors.

ECOLOGY	
Terrestrial Species and Populations	
Browsers and Grazers	14
Crops	14
Natural Vegetation	14
Pest Species	14
Upland Game Birds	14
Aquatic Species and Populations	
Commercial Fisheries	14
Natural Vegetation	14
Pest species	14
Sport Fish	14
Waterfowl	14
Terrestrial Habitats and Communities	
Food Web Index	12
Land Use	12
Rare & Endangered species	12
Species Diversity	14
Aquatic Habitats and Communities	
Food Web Index	12
Rare & Endangered species	12
River Characteristics	12
Species Diversity	14
Ecosystems	
Descriptive Only	

PHYSICAL / CHEMICAL	
Water Quality	
Basin Hydrologic Loss	20
Biochemical Oxygen Demand	25
Dissolved Oxygen	31
Fecal Coliforms	18
Inorganic Carbon	22
Inorganic Nitrogen	25
Inorganic Phosphate	28
Pesticides	16
pH	18
Stream Flow Variations	28
Temperature	28
Total Dissolved Solids	25
Toxic Substances	14
Turbidity	20
Air Quality	
Carbon Monoxide	5
Hydrocarbons	5
Nitrogen Oxides	10
Particulate Matter	12
Photochemical Oxidants	5
Sulphur Oxides	10
Other	5
Land Pollution	
Land Use	14
Soil Erosion	14
Noise Pollution	
Noise	4

Aesthetics

Land

Geologic surface Material	6
Relief & Topographical Character	16
Width and Alignment	10

Air

Odour and Visual	3
Sounds	2

Water

Appearance of Water	10
Land & Water Interface	16
Odour and Floating Material	6
Water Surface Area	10
Wooded & Geologic shoreline	10

Biota

Animals - Domestic	5
Animals - Wild	5
Diversity of Vegetation Types	9
Variety Within vegetation Types	5

Man Made Objects

Man Made Objects	10

Composition

Composite Effects	15
Unique Composition	15

Human Interest / Social

Education / Scientific

Archeological	13
Ecological	13
Geological	11
Hydrological	11

Historical

Architecture and Styles	11
Events	11
Persons	11
Religions and Cultures	11
Western Frontier	11

Cultures

Indians	14
Other Ethnic Groups	7
Religious Groups	7

Mood / Atmosphere

Awe Inspiration	11
Isolation / Solitude	11
Mystery	4
Oneness with Nature	11

Life Patterns

Employment Opportunities	13
Housing	13
Social Interactions	11

The flaws in this system are the arbitrary nature of the weighted scales applied to each factor, the anthrocentric focus of many of the factors and the numerous subjective value judgments that are required to be made. Although a reasonably broad range of ecological indicators are employed, the weightings given to entirely anthrocentric factors such as work opportunities, architectural styles and appearance of water are antipathetic to the development of an empirically verifiable environmental or more particularly ecological evaluation assessment. With some adaptation it may prove a useful system.

Matrix Systems

The following system developed by Environment Canada uses matrices to reveal indirect linkages between environmental components and in particular ecological interactions.

	Currents	Wind	Water temperature	Light	Intertidal Vegetation	Upland Vegetation	Bacteria	Insects	Larvae	Shellfish	Crabs	Other Crustaceans	Pelagic Fish	Bottom Fish	Water Birds	Birds Of Prey	Song Birds	Marsh and Shore Birds	Aquatic Mammals	Upland Mammals
Currents																				
Wind																				
Water temperature																				
Light																				
Intertidal Vegetation																				
Upland Vegetation																				
Bacteria																				
Insects																				
Larvae																				
Shellfish																				
Crabs																				
Other Crustaceans																				
Pelagic Fish																				
Bottom Fish																				
Water Birds																				
Birds Of Prey																				
Song Birds																				
Marsh and Shore Birds																				
Aquatic Mammals																				
Upland Mammals																				

These systems while useful in giving a qualitative analysis of a site or the effects of an intrusion into a site due to disruption of the matrix inter-reactions do not provide any quantitative analysis of the ecological state of the site or the degree of disruption due to an intrusion. They have limited use in application to ecological evaluation index development.

Networks

These are similar systems to matrices which highlight interactions in ecosystems. They use flow chart like graphics to describe ecosystem interactions and the possible effects of intrusions. They have the same limitations as the Matrix systems described above.

Biota Conservation Value Index

Developed from the National Parks and Wildlife Service, Tasmania, Wildlife Division Technical Report 86/2 (*Duncan, 1986*).

	Criteria	Index Value
		Hectares
i)	Area	50 1
ii)	Naturalness /Disturbance	Range 0 - 5 [2]
iii)	Biota Intensity	Range 0 - 5 [3]
iv)	Diversity - Species	Nº of Native Species
v)	Diversity Communities	Nº of Communities
vi)	Representativeness	Nº of Communities in fair to good condition
vii)	Conservation Significance - Species	
	a) Threatened	Nº x 10
	b) Poorly conserved or of other significance	No x 3
viii)	Conservation Significance - Communities	
	a) Local Scale	Nº poorly conserved
	b) Regional Scale	Nº poorly conserved
	c) Statewide Scale	Nº poorly conserved

Biota Conservation Index = S Indexes (i) ..... (viii)

1 ... The weighting recognises the greater inherent stability of larger areas from edge effects, small scale disturbances, tracks etc., and large scale disturbances, fires etc.

2 ... A score of 0 is applied to a severely modified locale (eg cleared, cultivated, quarried), a score of 5 is given to a site with negligible signs of European Land Use.

3 ... 0 = Desert, 1 = Savannah Tundra, 2 = Agricultural land, Grassland Steppes, Cool Temperate sclerophyll forest, 3 = Sub Tropical Sclerophyll Forest, Temperate Rainforest, Intense Agriculture, 4 = Tropical Jungle, Sub Tropical Rainforest, 5 = Equatorial Rainforest.

The arguable subjective evaluations in this system need closer examination as to their appropriateness:

i) for the land area, why divide hectares by 50. A fraction of area affected over the total area of the particular ecosystem being affected may give a more valid result ;

ii) why use ranges of 0 -5;

iii) why 'threatened species x 10' and 'poorly conserved x3'; what is the justification for these seemingly subjectively chosen numbers.

Even given these objections it is essential to chose an index system that has the potential to be widely used in the context of the analysis being made. As such this system, which has been used at least to some extent by the National Parks and Wildlife service and the various environmental authorities provides a strong initial starting point.

Developing and achieving scientific consensus on an appropriate absolute and consistent, state of the environment analysis and land degradation index is a high priority for research, this should lead to better indexes becoming available. Recognising these shortcomings and the current state of research, the framework for the application of any index, regardless of its appropriateness, to the task of ecological evaluation then becomes a vital issue for resolution.

If a consistent, absolute, quantitative, overall evaluation system identifies the requirements for indexes, these can be used to inform the index designers, to achieve more appropriate and applicable analysis. The EcoCost evaluation system is designed to be robust enough to employ similar indexing systems simultaneously, the major provision being that they are biologically rather than anthrocentrically focussed.

Appendix 4

Example Workthrough

A working through of the EcoCost system for two common building materials, Timber and Steel

including an analysis of Transport and Energy EcoCosts.

Example Workthrough

of the EcoCosting process using Steel and Timber.

The following workings show the data research and calculation paths that may be followed to give a reliable determination of ecological impact using the EcoCost Algorithm system. Two different (and often competing) materials, steel and timber, have been investigated to give a sense of comparison of the findings of the EcoCost system.

The nature of ecological impact evaluation determines that materials will have a varying EcoCost according to the location in which they are to be used. The calculations here take it that the site for the project involved is in the Hobart city area in Tasmania, Australia. The time of the EcoCost rating must also be specified to place it in its temporal environmental context, in this case 1994 in a building designed to last for 200 years in an industrial environment. The particular product chosen, and even the brand must be specified to gain a relevant EcoCosting due to the range of manufacturing processes and impact amelioration strategies employed by different manufacturers.

The materials analysed are:

- a sheet of corrugated steel from a big Australian steel supplier;

and

- an area of 135 x 19mm, Ship Lap Profiled Merchant Grade, Kiln Dried, Eucalyptus, Hard Wood Cladding from a major clearfell and milling operation in Tasmania's southern forests.

As a precursor to the calculations for these materials a determination of EcoCosts for energy use and transport requirements is necessary. These are therefore worked through first.

This workthrough has utilised available information sourced from widely disparate areas and has been limited by data constraints. In some areas the data used has been extrapolated from statistical reports and approximations from comparative sites and activities. This creates some degree of uncertainty with the particular results achieved, though in structure and general order of magnitudes they should be accurate enough to give a sense of the workings of the system. A great deal of further detailed research and data gathering will be required to enable the system to be reliably employed in fine grain decision making and resource allocation policy. At the level of analysis carried out here the results are to be viewed as indicative rather than absolute.

Careful note must be taken of the units (tonnes, mg, kg, metres, km, years etc) used in each level of analysis and evaluation to ensure consistency and compatibility of results.

An interesting and encouraging point to note is that the figures achieved for Land degradation and Toxic Impact for various processes have tended to be of the same order of magnitude without manipulation. This is most likely due to the use of the constant reference base of the planetary ecosystem and it subjectively indicates an intrinsic validity to the system.

The very small numbers being dealt with describing the evaluation as a fraction of the global ecosystem require doubling up of prefixes (PicoPico, $10^{-12} \times 10^{-12}$).
So, an impact of 1.0×10^{-24} Gaia is described as **1.0 PicoPicoGaia**

Energy Production

A determination of an EcoCost for energy begins with an identification of the energy sources which are used in the production of the particular artifact in question. Each separate energy source should then be investigated, finding the toxic output, land degradation and capital EcoCosts associated with the production of energy by that source. These figures can then be used to determine an EcoCost for each particular form of energy generation system involved and a final per GigaJoule (GJ) rating determined for the blend of energy sources used in the process.

Analysis shows that in Tasmania, overall energy consumption is supplied by four main sources; Oil, 41%; Hydro, 37%; Coal, 12%; Wood, 10%. (*Department of Primary Industry and Energy, 1988*) In an energy analysis it is assumed that this average distribution can be applied to the material's energy consumption figures. Thus the manufacturing energy for a product made in Tasmania could be EcoCosted out on the above proportions. Products manufactured in other areas should use the energy mix appropriate to that particular area.

Each particular energy source type will have a different EcoCost related to the ecological impact involved. Hydro Electric Energy, for instance will be low in Toxic Impact but high in Land Degradation, though this can be amortised over a long period of production (*H.E.C. ,1990*). Oil on the other hand will have a low Land Degradation component but a high Toxic Impact (*ABARE, 1992*). Coal will have a high Land Degradation component if open cast mined and a high toxic output if burnt in an inefficient way (*ABARE, 1992*). Coal will have a lower Land Degradation impact if underground mined and land restoration carried out and a lower toxic impact if, say, a fluidised bed and catalytic flue system of burning is used.

It is critical to differentiate between capital and ongoing ecological costs. Capital costs may be amortised over the productive life of the process being examined. Ongoing or recurrent impacts should relate to the unit production of energy. The Land Degradation involved in Hydro generation is predominantly part of the Capital Infrastructure. The large areas of land degraded by the storage dams, roads, villages, pipelines and generators all are Capital Infrastructure. With Coal the land degradation results from the mining, processing and attendant handling infrastructure and is part of ongoing ecological costs related to consumption. The land degradation figures for Natural Gas and oil relate to the well heads and extensive transfer pipeworks and refining installations and are part of ongoing costs.

Australia's industrial oil and gas come principally from the Bass Strait wells, a total of nearly 200km of undersea pipeline carries the raw materials from the sea rigs to the refineries near Port Welshpool. A 350km pipeline carries the refined fuel to depots in Melbourne, occupying 1.056 million square metres of land. The refineries, rig maintenance areas and construction yards occupy 1.2 million square metres. The oil refinery produces 20,312,688 tonnes per annum (*ABARE, 1992*).

Current nuclear fission technology requires large quantities of mineralised uranium ore (Yellowcake) to feed complex extraction and refinement processes for the plutonium fuel required. Energy generation results in small quantities of highly toxic residues that have to be safely stored for centuries, these will have a large EcoCost. Future fusion reactor technology should result in a much cleaner energy source using seawater as fuel and resulting in only small quantities of "hot" helium. The fuel consumption of nuclear reactors is extremely low in comparison to fossil fuel sources (*NATO Advanced Study Institute, 1973*).

Current technology exists for wind power, solar power, wave power, geothermal generation and hydro electricity (*Rainbow Power Company, 1993*). These are all renewable supply consuming sources of energy. Their original energy source is the sun and the action of the earth. Most of the EcoCost lies in the capital works and plant involved and the area of land taken up by potential storage and generating plant.

Hydro electric generation, as exists in Tasmania, has a high capital energy and land EcoCost but a very low ongoing generation EcoCost. Road area alone for Tasmania's Gordon scheme comes to some 780,000m^2 with the lakes taking up 514,000,000m^2 This scheme generates (at capacity) some 13,625,000 GJ of electrical energy in a year (*H.E.C. 1982 -94*). The dam and infrastructure has a design life of approximately 60 years (*Kellow 1982*) with a recovery period of about thirty years to a reasonable ecologically viable state and several hundred years to terminal ecosystems. An ameliorating factor may be that the land area subsumed by the water storage facility still has a high ecological biota support potential, albeit substantially different from the endemic situation.

Tasmania also uses an oil fired generator intermittently to back up the Hydro storage in dry years. This is sited on 250,000m^2 at bell Bay and generates energy at the rate of 0.64 GJ/tonne of oil (*H.E.C. 1982 -94*).

One tonne of coal burnt in a fuel powered generator system, given a 40% efficiency rating generates 9320 MJ of electrical energy

One thousand litres of Distillate gives 15,600 MJ.

One tonne of Natural Gas gives 19,880 MJ. (*Bousted & Hancock, 1974*)

Toxic Impact Energy

Data: (*U.S.A. E.P.A.; Greenberg, 1979; Parker, 1978*)

	LcLo's	Duration	Coal mg/GJ	Oil mg/GJ	Nat Gas mg/m3
Particles	985*	days**	633 000	125 000	150 000
SOx	3	months	1.87×10^6	1.1×10^6	8 000
CO	665	days	100 000	30 000	220 000
CO2	3213	years	1×10^8	8.0×10^7	6.0×10^7
HC's	200	days	50 000	25 000	40 000
NOx	103	months	750 000	500 000	2.3×10^6

One GJ of power from a coal burning generating station also results in a solid waste of 0.0048 tonnes of fly ash and 0.0029 tonnes of sulphur ash. Much of this is used in the building industry as aggregate and fill.

Hydro generation may occasionally cause large scale biological oxygen deficiency (BOD) and super-oxygenation of outflow waters though this is an accidental rather than normal effect.

* Some approximation is necessary with unidentified particulate matter, and waterborne suspended solids in terms of the assigned LCLo. Many different compounds are involved and clarification of what these substances are and their associated lethal concentrations is a priority research area. The LCLo's are expressed in mg/m^3.

** Only general approximations of duration of effect have been sourced at this stage, identification of accurate figures for this factor requires further detailed research as a priority. Duration of effect is expressed in terms of years or fractions thereof for the calculation.

Active Atmospheric Volume 3.373×10^{18} m^3

Planetary Life 4×10^9 years

Using the developed formula for toxic impact evaluation:

$$\text{Toxic Evaluation} = \frac{\text{Quantity of Output} \times \text{Duration of Effect}}{\text{Max Impact Conc.} \times \text{Total Ecosphere Vol.} \times \text{Planetary Life}}$$

Toxic Impact Calculations for Coal

Particles

Toxic evaluation = $(633000 \times 0.0192) / (985 \times 3.373 \times 10^{18} \times 4 \times 10^9)$

= 9.145×10^{-28}

SOx = 7.707×10^{-24}

CO = 2.14×10^{-28}

CO2 = 4.618×10^{-24}

HC's = 3.560×10^{-28}

NOx = 9.003×10^{-26}

Σ Toxic Impact = 1.241×10^{-23} Gaia / GJ

Toxic Impact Calculations for Oil

Particles

Toxic evaluation	=	$(125000 \times 0.0192) / (985 \times 3.373\times10^{18} \times 4\times10^{9})$
	=	1.80×10^{-28}
SOx	=	4.53×10^{-24}
CO	=	6.42×10^{-29}
CO_2	=	3.69×10^{-24}
HC's	=	1.78×10^{-28}
NOx	=	6.002×10^{-26}
Σ Toxic Impact	=	8.28×10^{-24} Gaia / GJ

Toxic Impact Calculations for Natural Gas

Particles

Toxic evaluation	=	$(150000 \times 0.0192) / (985 \times 3.373\times10^{18} \times 4\times10^{9})$
	=	2.16×10^{-28}
SOx	=	3.29×10^{-26}
CO	=	4.71×10^{-28}
CO_2	=	2.76×10^{-24}
HC's	=	2.85×10^{-28}
NOx	=	4.14×10^{-25}
Σ Toxic Impact	=	3.21×10^{-24} Gaia / GJ

Itinerate Impacts Factor Energy

An assessment of the limited nature of the resource should also be made using the resource sustainability evaluation suggested in the Bonus factor section ie;

$$\text{Evaluation} = \frac{\text{Quantity Consumed - Quantity Regenerated}}{\text{Quantity Remaining}} \times \frac{\text{Total (Bio)Mass Reserve}}{\text{Total Planetary (Bio)Mass}}$$

Land Degradation Energy

(H.E.C.; A.B.A.R.E.)	Coal	Nat.Gas	Dist.Oil	Hydro
Land Area utilised (m^2/GJ)	0.15	0.0061	0.0060	0.240 (capital)

The land degradation involved in electricity reticulation will require further investigation and has not been brought into these calculations at this stage. It is possible this will be a substantial impacted area.

The small land areas involved in Oil and Natural Gas land degradation make the effects insignificant in the EcoCost system. A closer analysis of the effects of long distance, large scale pipelines in sensitive ecologies will be required for improved analysis.

Land degradation analysis requires an assessment of land evaluation (using a land value index developed by the National Parks and Wildlife Service in Tasmania) of pre impact and post impact ecological state.

Coal Mining

Criteria	Calculation	Score Virgin	Score After
Area undisturbed	(212000/50) Max Score (20)	20	0
Naturalness/Disturbance		5	0
Diversity - Species		5	0
Diversity - Communities		3	0
Representativeness		3	0
Conservation Significance - Species			
Threatened		2	0
Poorly conserved		1	0
Conservation Significance - Communities			
Local scale		1	0
Regional Scale		3	0
Statewide Scale		1	0
	TOTAL	44	0
	Biota Conservation Index	44	0

(N.P.W.S. Tas & S.A.)

Post impact index 0 Pre impact index 44

Land Area used = 0.15 m^2/GJ

Planetary Land Surface Area (Total Ecosphere Area) 1.48×10^{14}

Duration of Effect 20 years mining + 30 years recovery

(approximated figures tentatively used here, further research required)

Planetary Life 4×10^9 years

$$\text{Impact Evaluation} = \left(1 - \frac{\text{Post Impact Index}}{\text{Pre Impact Index}}\right) \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

$$= (1 - 0/44) \times 0.15/1.48\times10^{14} \times 50/4\times10^{9}$$

$$= 1.27\times10^{-23}$$

= **12.7 PicoPicoGaia / GJ**

Capital works for Hydro Electric Schemes

Criteria	Score Virgin	Score After
Area undisturbed	(514000/50)	(10280)
Max Score (20)	20	0
Naturalness/Disturbance	5	3
Diversity - Species	12	5
Diversity - Communities	6	3
Representativeness	6	3
Conservation Significance - Species		
Threatened	2	1
Poorly conserved	1	1
Conservation Significance - Communities		
Local scale	1	2
Regional Scale	3	1
Statewide Scale	1	1
Total	57	20
Biota Conservation Index	57	20

(*N.P.W.S. Tas.*)

Post impact index 20 Pre impact index 57

Land Area used = 0.240 m^2/GJ average for Tasmanian Hydro

Planetary Land Surface Area (Total Ecosphere Area) 1.48×10^{14}

Duration of Effect 60 years operation (HEC Design Life) + 30 years recovery

Planetary Life 4×10^9 years

In the above case the land area has been amortised over the life output of the scheme to give an area per GJ figure, according to the formula:

$$\text{Land Area per GJ (Capital)} = \frac{\text{Total Land Area used}}{\text{Total Output over Life}} = \frac{\text{Total Land Area used}}{\text{Annual Output x Life of Installation}}$$

An alternative method would involve a calculation of the total effect of energy generation and then an amortising over the total production of the particular scheme with the formula:

$$\text{Land Deg. Eval} = \frac{\text{Evaluation}}{\text{Output over life}} = \frac{\text{Evaluation}}{\text{Annual Output x Expected Life}}$$

Both result in the same net result for the capital infrastructure EcoCost.

$$\text{Impact Evaluation} = \left(1 - \frac{\text{Post Impact Index}}{\text{Pre Impact Index}}\right) \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

$$= (1 - 20/57) \times 0.240/1.48 \times 10^{14} \times 90/4 \times 10^{9}$$

$$= 2.37 \times 10^{-23} \text{ Gaia/GJ}$$

$$= 23.7 \text{ PicoPicoGaia / GJ}$$

EcoCost Energy

Energy EcoCost = Land Deg + Toxic Impact + Capital EcoCost

$$\textbf{Capital EcoCost of Production} = \frac{\Sigma \text{ Land Degradation} + \Sigma \text{ Toxic Impact}}{\text{Life of Plant (expressed in GJ Output)}}$$

or

Energy Production EcoCost = LaE + ToE + CeE

Where

LaE* = Σ Land Degradation caused by energy production and fuel per GJ

ToE* = Σ Toxic Output Impact engendered in energy production per GJ

CeE = Capital EcoCost of Production Plant, amortised over life

that is ; $\dfrac{\Sigma \text{ Land Degradation} + \Sigma \text{ Toxic Output Impact}}{\text{Life of Plant (expressed in GJ Output)}}$

Note: Both the Land Degradation and Toxic Impact should include the gaining of the raw material, processing and transport to the generating facility of the fuel source, which will vary according to the location and system of the energy generation used.

Energy EcoCost of Coal

1.27×10^{-23} Land Degradation

2.133×10^{-23} Toxic Impact

Total 3.403×10^{-23}

Fuel Transport and refining EcoCost

One GJ requires 1.073 tonnes of coal

Energy EcoCost of Oil

8.28×10^{-24} Toxic Impact

Fuel Transport and refining EcoCost

One GJ requires 0.0541 tonnes of oil

Energy EcoCost of Natural Gas

3.21×10^{-24} Toxic Impact

Fuel Transport and refining EcoCost

One GJ requires 0.0503 tonnes of natural gas

Energy EcoCost of Hydro

2.37×10^{-23} Land Degradation

Also the EcoCost of the building of the dam, generating facilities and infrastructure, including materials use and construction, should be analysed and amortised over the life production of the facility.

Transport

An analysis of the transport requirement for a particular process requires a determination of the road, rail, sea and air distances involved in production and distribution. An further analysis of the impact of the particular methods of transport employed should then be made, this requires the following procedures:

- evaluating the toxic output impact and land degradation of fuel procurement and supply;
- evaluating the toxic output impact and land degradation of capital works for the transport infrastructure and for vehicles, amortised over the life of the infrastructure and/or vehicle in terms of tonne km.
- evaluating the impact of toxic output associated with the transporting vehicle (such as, fossil fuel burning).
- evaluating the ecological impact associated with wastage, used oil, parts, rubber and entire vehicles.

These constituent evaluations are then summed to give an overall per tonne km ecological impact evaluation for each form of transport and then this figure is multiplied by the transport distances involved for each stage of transport and the results summed.

The ecological costs relate to a direct consumption of fossil fuels and toxic release from exhausts. There is also added effect from wastage such as used sump oil and used tyres, both have low biodegradability and high toxin release when burnt. The photo block out caused by exhaust pollution reduces the incident solar energy available and adds to the impact.

In calculating the capital EcoCost of the vehicle, durability varies according to vehicle type and other unpredictable factors, a half life system is usually proposed to determine a general durability figure for transport vehicles. The half life is the period of time for half the original annual production of that vehicle to be off the road. This can then be used to give an average or median life of a vehicle for calculation purposes.

Land area analysis of transport is based on the number of tonne passes over a kilometre of the given roadway per annum. This leads to the corollary that the land cost for busy roads, ie main arterial systems, is much lower per tonne kilometre than little used country roads even given the substantial difference in area used.

Tasmanian Urban freeways clock up 20 million tonne passes per annum.

Main arterial highways average 4.85 million tonne passes p.a.

Secondary roads average 1 million tonne passes p.a.

Back roads average 200,000 tonne passes p.a. (*Tas.Dept. of Main Roads, 1988*)

Highway construction authorities in Australia currently base their costing projections on a twenty year active life for all road types before complete rebuilding is required. An ongoing maintenance program is required to achieve these lifespans. Arterial highways take up approx 8000m^2/km for the life of the road which is approximated at 22x10^6 passes.

More specific and accurate figures for various sections of the road network may be obtained from transport authority statistics, particularly traffic volumes annual surveys.

Internal combustion engined road transport is the predominant method of freight transferal in Tasmania. Roads occupy large areas of land and often traverse delicate ecosystems breaking up wildlife movement patterns and causing extensive impact on adjacent land. In Australia freight transport has reached figures of 32.9 billion km per annum with passenger transport (predominantly personal) achieving the grand total of 114 billion km. This gives a pollution outfall of 313 830 tonnes of particulate matter, 209 220, tonnes of sulphur dioxide, 7.81 million tonnes of carbon monoxide, 1.67 million tonnes of hydrocarbons and 2.23 million tonnes of nitrous oxides. (*Bureau of Transport & Communication Economics, 1991*)

Toxic Impact Transport

Data: (*U.S.A. E.P.A.; Greenberg, 1979; Parker, 1978*)

	LcLo's mg	Duration	I C mg/t.km	Diesel	Rail Diesel Extrapolated Figures
Particles	985	days	450	50	15
SOx	3	months	300	100	30
CO	665	days	11 200	800	230
CO2	3213	years	180 000	120 000	35 000
HC's	200	days	2400	130	38
NOx	103	months	3200	1300	380

Also - Tyre wear particulate emission 120 mg/tonne km (0.86 / tonne km)

Active Atmospheric Volume 3.373×10^{18} m^3

Planetary Life 4×10^9 years

Using the Formula developed for toxic impact evaluation:

$$\text{Toxic Evaluation} = \frac{\text{Quantity of Output} \times \text{Duration of Effect}}{\text{Max Impact Conc.} \times \text{Total Ecosphere Vol.} \times \text{Planetary Life}}$$

For IC engine 16tonne truck per tonne km:

Particles $= (\{450 + 120\} \times 0.0192) / (985 \times 3.37 \times 10^{18} \times 4 \times 10^9)$

$= 8.24 \times 10^{-31}$

SOx $= 1.855 \times 10^{-27}$

CO $= 2.40 \times 10^{-29}$

CO_2 $= 8.31 \times 10^{-27}$

HC's $= 1.71 \times 10^{-29}$

NOx $= 5.76 \times 10^{-28}$

$\Sigma = 1.078 \times 10^{-26}$ Gaia / tonne km

For Diesel engined 16tonne truck per tonne km.

$\Sigma = 8.94 \times 10^{-27}$

For Diesel powered Rail per tonne km

$\Sigma = 2.59 \times 10^{-27}$

For sea shipping (based on a 14000 tonne conventional bulk carrier)

$\Sigma = 4.38 \times 10^{-28}$

Land Degradation Transport

As with energy analysis, the separation of the land degradation due to transport into capital infrastructure and ongoing impact is essential. Capital infrastructure impact may be amortised over the life of the infrastructure in terms of the quantity of freight which they carry over their usable life.

The ongoing land degradation relates to the impact of fuel procurement and is insignificant for practical calculation purposes. The capital infrastructure land degradation is due to the roads, rail, ports, depots and parking required for the freighting of materials and is a major component of the overall EcoCost equation.

At this level a fairly random average level of pre impact land worth has been selected, for more detailed analysis a specific study of the particular road, rail or other area being affected will be required.

Criteria Calculation	Score Virgin	Score After
Area undisturbed (2/50)	1	0
Naturalness/Disturbance	3	0
Diversity - Species	4	0
Diversity - Communities	6	0
Representativeness	6	0
Conservation Significance - Species		
Threatened	2	0
Poorly conserved	1	0
Conservation Significance - Communities		
Local scale	1	0
Regional Scale	3	0
Statewide Scale	3	0
TOTAL	30	0
Biota Conservation Index	30	0

Pre Impact Index = 30 Post Impact Index = 0

Duration of Effect = 20 years average road design life + 30 years recovery

Planetary Life 4×10^9 years

Planetary Land Surface Area (Total Ecosphere Area) = 1.48×10^{14}

Area Utilised by Roads

$$\text{ea of Impact (per tonne km)} = \frac{\text{Total Road Area}}{\text{Number of tonne km Passes}} = \frac{\text{Road area per km}}{\text{Number of tonne passes}}$$

Urban	7.50×10^{-5}	m^2 / tonne km
Arterial	3.09×10^{-5}	
Secondary	8.0×10^{-4}	
Back Road	3.0×10^{-4}	

Rail Lines have an estimated life of between 50 to 100 years with current authority statistics and policy. This together with the huge tonne pass figures for regular freight lines makes land degradation for rail capital insignificant.

Using the formula developed for Land Degradation evalution:

$$\text{Impact Evaluation} = \left(1 - \frac{\text{Post Impact Index}}{\text{Pre Impact Index}}\right) \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

Urban Roads

Impact Evaluation = $(1- 0/30) \times 7.50\times10^{-5}/1.48\times10^{14} \times 50/4\times10^{9}$

Impact per tonne km = 6.33×10^{-27} Gaia

Arterial roads

Impact per tonne km = 2.61×10^{-27} Gaia

Secondary roads

Impact per tonne km = 6.75×10^{-26} Gaia

Back roads

Impact per tonne km = 2.53×10^{-26} Gaia

Rail

Impact per tonne km - insignificant

Transport Impact = Σ Transport Distances x (Σ Land Degradation + Σ toxic Impact + Σ Capital Impact vehicle + Σ Capital Impact Infrastructure)

or

Transport EcoCost = Td x Σ (LaT + ToT + CeT + CeI)

Where Td = Transport distances for each transport type

LaT = Σ Land Degradation caused by fuel procurement and operation

ToT = Σ Toxic Output Impact of transporting vehicle per tonne km

CeT = Capital EcoCost of Transporting vehicle per tonne km

that is ; $\dfrac{\Sigma \text{ Land Degradation} + \Sigma \text{ Toxic Output Impact}}{\text{Life of Vehicle (expressed in tonne km)}}$

CeI = Capital Infrastructure EcoCost, amortised over life per tonne km

that is; $\dfrac{\Sigma \text{ Land Degradation} + \Sigma \text{ Toxic Output Impact}}{\text{Life of Infrastructure (expressed in tonne passes)}}$

At this level of analysis the ongoing component land degradation of transport and the Capital cost of the vehicle have been considered insignificant and left out of the calculation. The impact evaluation is then a summation of the toxic impact of exhaust emmissions per tonne km and an amortised land degradtion of the capital infrastructure of the roads.

Diesel Truck on Urban Roads = **8.94×10^{-27} + 6.33×10^{-27}**
= **1.52×10^{-26}**
= **0.0152 PicoPicoGaia / tonne km**

Diesel Truck on Arterial Roads = **8.94×10^{-27} + 2.61×10^{-27}**
= **1.16×10^{-26}**
= **0.0116 PicoPicoGaia / tonne km**

Diesel Truck on Secondary Roads = **8.94×10^{-27} + 6.75×10^{-26}**
= **7.644×10^{-26}**
= **0.0765 PicoPicoGaia / tonne km**

Diesel Truck on Back Roads = **8.94×10^{-27} + 2.53×10^{-26}**
= **3.424×10^{-26}**
= **0.0342 PicoPicoGaia / tonne km**

For Diesel powered Rail = **2.59×10^{-27}**
= **0.0026 PicoPicoGaia / tonne km**

For sea shipping (based on a 14000 tonne conventional bulk carrier)
= **4.38×10^{-28}**
= **0.00044 PicoPicoGaia / tonne km**

Steels

Energy EcoCosts for the mining and manufacture of the steel were gained from existing data (*Bousted and Hancock, 1974*). The method of energy production for the mining and mill areas were identified and the appropriate energy production EcoCosts applied.

Transport costs were determined by finding out the distances travelled and transport systems used in gaining the ore, getting it to the mill, moving the refined steel to the various processing plants and transport to the local distribution centres.

The land area degraded for the raw material gathering was assessed by finding the area of the mine site and dividing this by the total product of the mine to date. (*Metal and Engineering Workers Union, 1993*).

The land value is still unfinalised but figures (*National Parks and Wildlife, 1993*) for adjacent areas have been used to give an approximation of the land worth before mining.

The pollutant output for the manufacturing process used at Whyalla steel mills (which provide Australia's domestic supply) , ie open electric blast furnacing and hot continuous tapping, was assessed by taking the figures from the AP-42 U.S.A. E.P.A. *Compilation of air pollution emission factors* and the U.S.A. E.P.A. *New Source Performance standards (effluents)* for this process.

	Mild Steel	Stainless	Galvanised	Galv Sheet
Production Energy Requirements GJ/Tonne	52	80	53	59

Production Plant Location	Whyalla, Newcastle & Port Kembla	
Raw material Location	Middleback Range S.A. 50km to mill	
Land Area	0.934 m^2/tonne mining, 1.809 m^2/tonne with mill	
Density	7900 kg/m^3	
Durability		
Marine Environment-	100% in 2 Years	
Industrial Env.	-	100% in 13 Years
Rural Environment	-	20% in 20 Years
		100% in 100 Years (extrapolated)
Galvanised Sheet Steel roofing	40 Years+	

Energy Consumption in manufacture can vary considerably from 50.0 to 97.5 GJ/Tonne (Fabricated) according to alloy and process

Raw Materials : Iron Ore is extracted from open cut mines consuming prodigious amounts of rock, crushing and magnetically separating out richer ore and depositing overburden and crushings as a waste product. The mines in the Middleback Ranges currently supplying the Australian domestic market occupy 2895 Ha. and produce 2.5 million tonnes of high grade ore, 62%Fe, annually.

Coke is a basic ingredient in the alloying process, once again usually procured in open cut mines, of a smaller scale. 800kg of coke are required for the production of a tonne of steel.

Large quantities of limestone are also required in the smelting process. 2.5 million tons are used annually

Copper, nickel, molybenedium, tungsten, zinc, and various other metals are also employed in the various alloying processes for different steel types. Most of these are procured in underground mines and due to the low purity of ores are processed close to the mine head. Mechanical and then chemical extraction procedures are employed, often leading to high pollution outfalls at the mine site. Large quantities of waste material and slag are generated. 6500 tonnes of ferro manganese are used annually.

Transportation : The ore is usually transported "as is" to the smelting mills. In Australia all local steel is made from iron ore procured in the Middleback Range and shipped 50km to the Whyalla steel mills by rail or on to Newcastle or Port Kembla 3600km by sea.

A 223km water pipeline is maintained to supply water to the mill at Whyalla.

An extensive rail network, 320km in length, links all the Middleback mines to the mill at Whyalla.

Processing : At the smelting mills, occupying a site of 770Ha, iron is extracted from the ore and alloyed to produce steels in blast furnaces, consuming large quantities of energy. Coke limestone and manganese ore are used in the production of Australian steel. There are electric, gas and oil fired blast furnaces. Other metals, such as nickel for stainless steel and tungsten for tool steel, manganese and silicon for structural steels are added in the alloying stages.

The raw steel is then cast, milled, rolled, profiled and machined to create the extensive array of structural forms available.

The structural profiles are then fabricated into architectural forms utilising high energy cutting and welding procedures. Advanced forms require special castings, machinings and assembly.

Whyalla produces 320,000 of structural steel and 120,000 tonnes of rail per annum and is expected to last for at least twenty years.

Special pollution Problems : high dust output (7-11 kg/tonne output), smoke occlusion problems from blast furnaces, Sulphur oxides, carbon monoxide, cyanides and toxic metal oxides. (*Greenberg, 1979; Parker, 1978*)

Finishes : Most steels are unstable in the environment and require weather resistant coatings, galvanising, painting, sacrificial anodes etc.

Some steel alloys are resistant to corrosion and wear but are more difficult to manufacture and will probably have a higher base EcoCost,eg Stainless Steel, CoreTen.

The base EcoCost of a coating system may be offset by greater longevity and ability to withstand weathering. Each individual coating system will require analysis.

Coatings such as zinc have a high energy and pollutant outfall cost in themselves.

Steels are heavy but have high strength and rigidity in small volumes. They are reliably, consistent and predictable in they actions under loading. They are flexible and with current technology can be made into virtually any form.

Steels are the result of an extensive industrialised network, they require an organised heirachy of processes to become building elements. Large transportation requirements must be met due to weight of the product.

Steels can be re-used ad nauseum provided they do not fall foul to corrosion

Durability : Steels have a usable lifespan of between twenty and two hundred years in a structural system depending on location and alloy. Most steels are highly susceptible to corrosion particularly in marine or industrial environments. Steels need protection from the elements especially moisture. Coating systems dramatically improve the durability of steels. (*Eldridge, 1974*)

Toxic Impact Steel

Data: (*U.S.A. E.P.A.; Greenberg, 1979; Parker, 1978*)

	LcLo's	Duration	Mild Steel (industry average.) mg/tonne
Particles	985	days	1.38×10^6
SOx	3	months	1.08×10^6
CO	665	days	0.27×10^6
CO2	3213	years	-
HC's	200	days	0.15×10^6
NOx	103	months	0.25×10^6
Ozone	2	days	
BOD	2	days	0.34×10^6
COD	2	days	1.44×10^6
TSS	250 (average)	months	0.54×10^6
Dis Sol	100 (average)	decades	7.2×10^6

Active Atmospheric Volume 3.373×10^{18} m^3

Planetary Life 4×10^9 years

Using the formula developed for toxic impact:

$$\text{Toxic Evaluation} = \frac{\text{Quantity of Output} \times \text{Duration of Effect}}{\text{Max Impact Conc.} \times \text{Total Ecosphere Vol.} \times \text{Planetary Life}}$$

For Mild Steel per tonne:

Particles	=	$(1.38 \times 10^6 \times 0.0192) / (985 \times 3.37 \times 10^{18} \times 4 \times 10^9)$
	=	1.99×10^{-27}
SOx	=	6.68×10^{-24}
CO	=	5.78×10^{-28}
CO_2	=	-
HC's	=	1.07×10^{-27}
NOx	=	3.00×10^{-26}
BOD	=	2.42×10^{-25}
COD	=	1.025×10^{-24}
TSS	=	2.67×10^{-26}
DisSol	=	1.335×10^{-22}

Σ Toxic Impact = 1.415×10^{-22} Gaia / tonne

= **141.5 PicoPicoGaia / tonne**

Land Degradation Steel

Analysis of the degradation caused by open cut mining for iron ore mining in the Middleback Ranges by applying the Biota Conservation Index. (*extrapolated from N.P.W.S. data*)

Criteria	Calculation	Score Virgin	Score After
Area undisturbed	(2600/50)	20	0
Naturalness/Disturbance		5	0
Diversity - Species		8	3
Diversity - Communities		6	1
Representativeness		6	1
Conservation Significance - Species			
Threatened		2	0
Poorly conserved		3	0
Conservation Significance - Communities			
Local scale		1	0
Regional Scale		3	0
Statewide Scale		1	0
	Total	55	5
	Biota Conservation Index	55	5

Pre Impact Index = 55

Post Impact Index = 5

Land Area = 0.934 m^2/tonne mining, 1.809 m^2/tonne with mill

Duration of Effect = 20 year mining + 30 years recovery

Planetary Life = 4×10^9 years

Planetary Land Surface Area (Total Ecosphere Area) = 1.48×10^{14}

Using the formula developed for land degradation evaluation:

$$\text{Impact Evaluation} = \left(1 - \frac{\text{Post Impact Index}}{\text{Pre Impact Index}}\right) \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

Impact Evaluation $= (1 - 5/55) \times 1.809/(1.48 \times 10^{14}) \times 50/(4 \times 10^{9})$

$= \mathbf{1.389 \times 10^{-22}}$

$=$ **138.9 PicoPicoGaia**

Land Degradation Coke

Post impact index	0
Pre impact index	44
Land Area used	= 0.14 m^2/tonne
Planetary Land Surface	Area (Total Ecosphere Area) 1.48×10^{14}
Duration of Effect	20 years mining + 30 years recovery
Planetary Life	4×10^9 years

$$\text{Impact Evaluation} = \left(1 - \frac{\text{Post Impact Index}}{\text{Pre Impact Index}}\right) \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

$= (1 - 0/44) \times 0.14/1.48 \times 10^{14} \times 50/4 \times 10^{9}$

$= 1.18 \times 10^{-23}$ Gaia/tonne

= 11.8 PicoPicoGaia / tonne (coke)

800kg of coke are required to produce one tonne of steel

Land Degradation of coke supply = 11.8 x 0.8 = 9.44 PicoPicoGaia / tonne

Land Degradation Limestone

Post impact index	3
Pre impact index	58
Land Area used	= 0.036 m^2/tonne
Planetary Land Surface	Area (Total Ecosphere Area) 1.48×10^{14}
Duration of Effect	20 years mining + 30 years recovery
Planetary Life	4×10^9 years

$$\text{Impact Evaluation} = \left(1 - \frac{\text{Post Impact Index}}{\text{Pre Impact Index}}\right) \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

$= (1 - 3/58) \times 0.036/1.48 \times 10^{14} \times 50/4 \times 10^{9}$

$= 2.803 \times 10^{-24}$

= 2.80 PicoPicoGaia / tonne (Limestone)

1.613 tonnes of limestone are required to produce one tonne of steel

Land Degradation of limestone supply = 2.80 x 1.613

= 4.52 PicoPicoGaia / tonne

Additional data for manganese, zinc, copper and other additives for the manufacturing and alloy processes will need to be researched for a more accurate and detailed analysis of the steel manufacturing process.

Σ Land Degradation

The land degradation figures for each constituent of the process are then summed to provide an overall figure for the production of a tonne of steel.

Land Degradation = **138.9 + 9.44 + 4.52**
= **152.85 PicoPicoGaia / tonne Steel**

Transport Evaluation Steel

50 km rail as ore to mill - 5.68 tonnes ore carried for each tonne of finished steel produced

284 tonne km rail per tonne product

Impact = 284 x 2.59×10^{-27} = 7.356×10^{-25} = 0.74 PicoPicoGaia

2400 sea km to Newcastle for profiling and 1200 sea km to Hobart

3600 tonne km per tonne product

Impact = 3600 x 4.38×10^{-28} = 1.58×10^{-24} = 1.58 PicoPicoGaia

20 road km by diesel engined truck to vendor and on to site.

20 tonnekm per tonne product

Impact = 20 x 8.94×10^{-27} = 1.788×10^{-25} = 0.18 PicoPicoGaia

Total Transport Impact = 2.5 PicoPicoGaia / tonne

Energy Evaluation Steel

The energy requirements for the production of Steel are broken down as follows (*Department of Primary Industry and Energy, 1988*)

Coal	Petrol	Nat Gas	Elec. (Coal Fired)
62%	2%	21%	15%

Energy EcoCost of Coal

1.27×10^{-23} Land Degradation 1.241×10^{-23} Toxic Impact

Fuel Transport and refining EcoCost

One tonne of coal gives 0.932 GJ One GJ requires 1.073 tonnes of coal

430 tonne km rail per GJ **= 430 x 2.59×10^{-27} = 1.11×10^{-24}**

Total 2.622×10^{-23} = **26.22 PicoPicoGaia /GJ**

Energy EcoCost of Oil

8.28×10^{-24} Toxic Impact

Fuel Transport and refining EcoCost

One tonne oil gives 18.5 GJ One GJ requires 0.0541 tonnes of oil

35 tonne km of rail per GJ **= 35 x 2.59×10^{-27} = 9.06×10^{-26}**

Total 8.37×10^{-24} = **8.37 PicoPicoGaia /GJ**

Energy EcoCost of Natural Gas

3.21×10^{-24} Toxic Impact

Fuel Transport and refining EcoCost

One tonne of nat. gas gives 19.88 GJ One GJ requires 0.0503 tonnes of gas

30 tonne km of rail per GJ **= 30 x 2.59×10^{-27} = 7.77×10^{-26}**

Total 3.29×10^{-24} = **3.29 PicoPicoGaia /GJ**

Energy EcoCost of Hydro

3.418×10^{-23} Land Degradation

Total 2.37×10^{-23} = **23.7 PicoPicoGaia /GJ**

Overall Energy EcoCost

From the proportions of energy use an overall EcoCost per GJ can be calculated to be (for energy used in steel production at Whyalla refineries)

Total 2.791×10^{-23} = **27.91 PicoPicoGaia /GJ**

This figure can then be multiplied by the energy consumption figure for steel production (*Bousted & Hancock, 1974*).

	Mild Steel	Stainless	Galvanised	Galv Sheet
Production Energy	**52**	**80**	**53**	**59**
Energy EcoCost per tonne in PicoPicoGaia	**1074.82**	**1653.57**	**1095.49**	**1219.51**

Itinerate Impacts Factor

There is insufficient data at this stage to make a valid analysis of the Itinerate Impacts Factor parameters. So, these will be left in abeyance pending further research and data.

An assessment of the limited nature of the resource should also be made using the resource sustainability evaluation suggested in the Bonus factor section ie;

$$\text{Evaluation} = \frac{\text{Quantity Consumed - Quantity Regenerated}}{\text{Quantity Remaining}} \times \frac{\text{Total (Bio)Mass Reserve}}{\text{Total Planetary (Bio)Mass}}$$

Given the vast nature of current iron ore reserves this figure is unlikely to make an impact on the EcoCost calculations for steel production. Its relevance to an ecological evaluation system in the case of non biological resources is also questionable.

Longevity

The steel is assumed to be treated in such a way as to give it a minimum life expectancy of 90 years.

With a building design life expectancy of 200 years a longevity figure of

$$\text{Longevity} = \frac{\text{Life of material}}{\text{Expected Building Life}} = \mathbf{0.45}$$

EcoCost Calculation Mild Steel

Using the figures derived above and putting them into the EcoCost algorithm.

$$\text{EcoCost of Material} = \left(\frac{La + To + Ec + Td + \beta}{\text{Longevity}}\right) \times Re + ReE$$

Where	La	=	Σ Land Degradation Evaluations	=	152.85
	To	=	Σ Toxic Output Impact Evaluations	=	141.5
	Ec	=	Energy Consumption x Energy Production	=	1451.63
	Td	=	Transport Distance x Transport	=	2.5
	β	=	Ecological Impact Bonus/Penalty		
	Re	=	Recycled / Reused proportion factor	=	1
	ReE	=	EcoCost of recycled / reused portion.	=	0
	Longevity	=	$\frac{\text{Life of material}}{\text{Expected Building Life}}$	=	0.45

EcoCost of Material = (152.85 + 141.5 + 1219.51 + 2.5)/0.45

= 3369.70 PicoPicoGaia / tonne

A square metre of corrugated galvanised cladding at 0.75mm thick gives a steel volume of $0.0012m^3$, at a density of 7900kg / m^3 this gives 0.0095 tonnes / m^2 of cladding.

The EcoCost per m^2 of cladding is thus :

0.0095 x 3885.5 = 32.0 PicoPicoGaia

Timber

The following figures relate specifically to the Tasmanian southern forests commercial logging operations supplying commercial large scale milling and kiln drying operations.

Energy consumption figures for timber production have been taken from research Working Papers of the Department of Environmental Studies, University of Tasmania.

Land degradation figures are taken from Tasmanian National Parks and Wildlife and Tasmanian Forestry Commission reports on logging operations.

	Plantation	Clearfell	Dressed
Production Energy Requirements GJ/Tonne	5.8 ?	6.5	6.75

Production Plant Location	Widespread (see Forestry commission)
Raw material Location	Local. (Domestic Supply)
Land Area Degradation	$38 m^2$ per Tonne (Clearfell, 20 Year regrowth
Density	560 (light pines) - 1200 (dense gums) kgm^3

Durability varies widely according to species; see timber properties chart.

Timber will need to be divided into a number of sub-categories according to species, exoticity or endemicity, method of harvesting, finish and grades used. In almost all areas of Tasmania there are local sawmillers extracting endemic timbers from either plantation, regrowth or selectively from old growth forests, these generally have lower ecological impact than large scale, clear fell operations that tend to utilise predominantly old growth areas at present and for the next decade or so.

There are many species of timber imported from overseas these obviously have a higher transport EcoCost component. Some research has to be done to determine the harvesting and ecological strategies of the countries of origin.

Rarer species in all areas, especially slower growing species are at greater peril of being exterminated and hence will have a high EcoCost attached.

The principal portion of the EcoCost associated with timber usage lies in the land area destroyed by harvesting and the regrowth time required to re-establish original conditions. By mathematically plotting the quantitative regrowth against time and using integration techniques to determine the long term land degradation effects a truer figure may be obtained. This would have to be modified by the ecological worth of the regrowth system employed. However, at the level of analysis carried out here, a simplistic figure of recovery period is used (pending further research).

The harvesting of timber is the direct consumption of biota, the breathing capability (detoxifying effect) of the plant lost should be considered. These factors will have to be dealt with by Itinerate Impact Factor parameters when research and data become available.

Raw material - Renewable Resource ! Timber is a product of a direct conversion of incident solar energy and atmospheric carbon dioxide into a usable product, the ultimate in living machines for sustainable resource production. The problem comes with how the resource is accessed and managed. If managed properly it is a low impact, sustainable resource, if mismanaged, high environmental and ecological impacts result from ecosystem degradation.

Transport - Usually moderate transport requirements from source to mill but this varies according to species used, harvesting and production processes and site of harvesting.

Processing - Low tech and relatively low energy process, labour intensive due to the skill based complexity of the task. Fuel motor driven saws predominate with some electrical systems around. Either a time factor required for air drying or an energy input for kiln or humidifier drying, this varies according to manufacturer but most use some form of kilning to a lesser or greater degree.

The production process produces sawdust as its primary waste product, in some cases this is utilised either for compost, mulch, fuel and even composite board manufacture.

There is insignificant pollution or Toxic Impact associated with the production of timber to warrant a specific calculation. Toxic impact associated with energy generation and transport will be covered by those analysis

Treatments - Some species have naturally high resistance to weathering and require little or no treatment. Most timbers require some form of surface stabilisation and anti-rotting treatment. Paints, oils, varnishes, poly urethanes, resin treatments are all used. Treatments vary from high to moderate toxicity.

Durability varies widely according to species, treatment and construction techniques.

Timber varies in strength dramatically according to species, dryness and application.

Technological recycling of timber is not yet carried out though the natural system is highly advanced. Timber is easily reused though problems of workability, foreign bodies and hardness are often struck.

Toxic Impact Timber

The toxic impact associated with the production of timber apart from that required for energy generation and transport is insignificant.

Land Degradation Timber

Clearfell

(figures extrapolated from *N.P.W.S. Tas Forestry Commision Tas. reports*)

Criteria	Calculation	Score Virgin	Score After
Area undisturbed	(600/50)	12	0
Naturalness/Disturbance		5	0
Diversity - Species		12	3
Diversity - Communities		6	1
Representativeness		6	1
Conservation Significance - Species			
Threatened		2	0
Poorly conserved		3	0
Conservation Significance - Communities			
Local scale		1	0
Regional Scale		3	0
Statewide Scale		1	0
	Total	51	5
	Biota Conservation Index	51	5

Area = 38 m^2/tonne

Pre Impact Index = 51

Post Impact Index = 5

Duration of Effect = 1 year harvesting 30 years recovery

Planetary Life = 4×10^9 years

Planetary Land Surface Area (Total Ecosphere Area) = 1.48×10^{14}

$$\text{Impact Evaluation} = \left(1 - \frac{\text{Post Impact Index}}{\text{Pre Impact Index}}\right) \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

Impact Evaluation = $(1 - 5/51) \times 38/(1.48 \times 10^{14}) \times 30/(4 \times 10^9)$

= 1.74×10^{-21}

= **1740 PicoPicoGaia / tonne**

As a contrast to clearfell the impact for selectively logged timber is given.

(figures extrapolated from *N.P.W.S. Tas Forestry Commision Tas. reports*)

Criteria	Calculation	Score Virgin	Score After
Area undisturbed	(600/50)	12	8
Naturalness/Disturbance		5	3
Diversity - Species		12	11
Diversity - Communities		6	5
Representativeness		6	6
Conservation Significance - Species			
Threatened		2	2
Poorly conserved		3	3
Conservation Significance - Communities			
Local scale		1	1
Regional Scale		3	3
Statewide Scale		1	1
Total		51	43
Biota Conservation Index		51	43

Area = 38 m^2/tonne

Pre Impact Index = 51

Post Impact Index = 43

Duration of Effect = 2 to 10 years recovery depending on management

Planetary Life = 4×10^9 years

Planetary Land Surface Area (Total Ecosphere Area) = 1.48×10^{14}

$$\text{Impact Evaluation} = \left(1 - \frac{\text{Post Impact Index}}{\text{Pre Impact Index}}\right) \times \frac{\text{Area Affected}}{\text{Total Ecosphere Area}} \times \frac{\text{Duration of Effect}}{\text{Planetary Life}}$$

Impact Evaluation $= (1 - 43/51) \times 38/(1.48 \times 10^{14}) \times 5/(4 \times 10^9)$

$= 5.035 \times 10^{-23}$ Gaia/tonne

= **50.35 PicoPicoGaia / tonne**

Transport Evaluation Timber

All road km are by diesel engined truck but on various road types.

30 km (average.) back road as logs to mill - 1.6 tonnes of logs carried for each tonne of finished timber produced - 48 tonne km per tonne of timber produced

Impact Evaluation = 48 x 0.0342 = 1.64 PicoPicoGaia / tonne

60 km secondary road as timber to Hobart for profiling

Impact Evaluation = 60 x 0.0765 = 4.59 PicoPicoGaia / tonne

20 arterial road km to vendor and on to site.

Impact Evaluation = 20 x 0.0116 = 0.23 PicoPicoGaia / tonne

Total Transport Impact = 6.46 PicoPicoGaia / tonne

Energy Evaluation Timber

The energy requirements for the production of Timber in Tasmania are broken down as follows: (*Dept of Primary Industry and Energy, 1988*)

Petrol	Elec. (hydro)
88%	12%

Energy EcoCost of Oil
8.28×10^{-24} Toxic Impact
Fuel Transport and refining EcoCost
One tonne oil gives 18.5 GJ One GJ requires 0.0541 tonnes of oil
35 tonne km of sea per GJ **= 35 x 4.38×10^{-28} = 1.54×10^{-26}**
Total 8.30×10^{-24} = **8.30 PicoPicoGaia /GJ**

Energy EcoCost of Hydro
3.418×10^{-23} Land Degradation
Total 2.37×10^{-23} = **23.7 PicoPicoGaia /GJ**

Overall Energy EcoCost

From the proportions of energy use an overall EcoCost per GJ can be calculated to be (for energy used in timber production in Tasmania refineries)

Total **10.14 PicoPicoGaia /GJ**

This figure can then be multiplied by the energy consumption figure for steel production.

	Plantation	Clearfell	Dressed
Production Energy Requirements	**5.8 ?**	**6.5**	**6.75**
Energy EcoCost per tonne in PicoPicoGaia	**58.85**	**65.96**	**68.50**

Bonus Factor

There is insufficient data at this stage to make a valid analysis of the Bonus Factor parameters. So, these will be left in abeyance pending further research.

Longevity

The timber is assumed to be chosen, detailed and treated in such a way as to give it a minimum life expectancy of 50 years.

With a building design life expectancy of 200 years a longevity figure of

$$\text{Longevity} = \frac{\text{Life of material}}{\text{Expected Building Life}} = \mathbf{0.25}$$

EcoCost Calculation Clearfell Timber

Using the figures derived above and putting them into the EcoCost algorithm.

$$\textbf{EcoCost of Material} = \left(\frac{La + To + Ec + Td + \beta}{\text{Longevity}}\right) \times Re + ReE$$

Where	La	=	Σ Land Degradation Evaluations	=	**1740**
	To	=	Σ Toxic Output Impact Evaluations	=	**-**
	Ec	=	Energy Consumption x Energy Production	=	**74.5**
	Td	=	Transport Distance x Transport	=	**6.46**
	β	=	Ecological Impact Bonus/Penalty		
	Re	=	Recycled / Reused proportion factor	=	**1**
	ReE	=	EcoCost of recycled / reused portion.	=	**0**
	Longevity	=	$\frac{\text{Life of material}}{\text{Expected Building Life}}$	=	**0.25**

EcoCost of Clearfell Timber = (1740 + 68.50 + 6.46)/0.25

= 7259.84 PicoPicoGaia / tonne

A square metre of cladding at 19mm thick gives a timber volume of $0.019 m^3$, at a density of $950 kg / m^3$ this gives 0.0181 tonnes / m^2 of cladding. The EcoCost per m^2 of cladding is thus :

0.0181 x 7259.84 = 131.40 PicoPicoGaia

Comparing this to the result for a square metre coverage of corrugated steel sheet of 32.00 PicoPicoGaia shows a marked ecological benefit in using steel sheet over clearfell timber cladding.

EcoCost Calculation Selective Logged Timber

Using the figures derived above for selectively logged timber, adding a quality building component of timber treated to last a full 200 years and putting them into the EcoCost algorithm as a comparison.

$$\textbf{EcoCost of Material} = \left(\frac{La + To + Ec + Td + \beta}{Longevity}\right) \times Re + ReE$$

Where	La	=	Σ Land Degradation Evaluations	=	**50.35**
	To	=	Σ Toxic Output Impact Evaluations	=	-
	Ec	=	Energy Consumption x Energy Production	=	**74.5**
	Td	=	Transport Distance x Transport	=	**6.46**
	β	=	Ecological Impact Bonus/Penalty		
	Re	=	Recycled / Reused proportion factor	=	**1**
	ReE	=	EcoCost of recycled / reused portion.	=	**0**
	Longevity	=	Life of material / Expected Building Life	=	**1.0**

EcoCost of Material = (50.35 + 68.50 + 6.46)/1.0

= 125.31 PicoPicoGaia / tonne

or 1.8% of the clearfell, poor construction technique figure !

A square metre of cladding at 19mm thick gives a timber volume of $0.019m^3$, at a density of 950kg / m^3 this gives 0.0181 tonnes / m^2 of cladding. The EcoCost per m^2 of cladding is thus :

0.0181 x 125.31 = 2.27 PicoPicoGaia

Comparing this to the result for both a square metre coverage of corrugated steel sheet of 32.00 PicoPicoGaia and of Clearfell timber at 131.40PicoPicoGaia shows a reversal in the situation and marked ecological benefit in using selectively logged timber for cladding over steel sheet over clearfell timber cladding.

In a remote area where there is no local source of timber this may well alter again due to the much lower mass of steel required for transportation ecological cost calculations.

Addenda A

Timber Strength and Durability Tables by Species

Species		Strength Rating		Durability Rating
Eucalypts				
	Tas. Blue Gum	SD4	F17+	2
	IronBark	SD1	F23+	4
	StringyBark	SD3	F14+	3
Pines				
	Baltic		F5	1B
	Celery Top	SD5	F14	3
	Huon		F8	4
	Hoop	SD5		1B
	Radiata	SD7	F8	1A
	Oregon		F5	
	Western Red Cedar		F5	
Blackwood			F14	3
Jarrah		SD4	F14	
Karri		SD2	F17	1B
Mercanti			F8	1A
Sassafras				1A
Tallowwood		SD2		4

The strength ratings given are for seasoned dry timber and indicate the potential of the timber species to reach maximum stress grading according to the Mechanical and Visual grading system (F. ratings).
SD8 indicates a weak timber F5 Max.
SD1 has the potential to be a very strong timber up to F23 and beyond.

The durability figures given are an indication of the timbers species ability to resist decay, rot, and weathering according to the following scale;

1A Indoor Use only for unprotected timber
1B Exterior Use only in Sheltered areas and with protective coatings
2 some weathering resistance needs protection for long term applications
3 Weather and marine environment resistant.
4 Suitable for long term use as poles, stumps and in very exposed and maritime locations.

Information from the

Timber Reference Manual
Timber Promotion Council. Blackburn, Aust. 1979

Addenda B

Bits and Pieces

Material	density Kg/M3	tensile strength MPa	comp strength MPa	Elastic modulus MPa	Thermal Expansion Coef	Moisture Shrinkage %	
Aluminium	2650	75	70 000	24	nil		
Alloy	2700	300		70 000	23	nil	
Brass	8400	400		100 000	21	nil	
Cast Iron	7200	100-600		180 000	10	nil	
Clay Bricks	1900	0.02-0.04	20-80			-0.08	
Concrete	300-2400	2-6	14-50	10-28000	12	0.03-0.05	
Copper	8700	220-360		120 000		nil	
Glass	2500	15-150	100-300	70 000	9	nil	
lead	1120	17		14 000	30	nil	
Magnesium Alloy	1760	140-280		45 000		nil	
PVC	1350	60		25 000			
Polystyrene	1120	95			70		
Stone							
Granite	2240		100-200		11		
Limestone	1800-3000		40-150		3		
Marble			70		4		
Sandstone			25-75		12		
slate			50-70				
Steel	8100	1700		200 000	10	nil	
Hardened	8000	1400		200 000	11	nil	
Stainless	8100	960		200 000	11	nil	
structural	7900	480	160	200 000	12	nil	
Timber	green to	12%	Moisture Content	(dry)		rad.	tang.
Douglas Fir	650 -560	55	2-10	10-12 000	4.5	2.5	4
Grey Gum	1300-1050	55	17-20	5-16	16-21000		

Addenda C

More Bits and Pieces

Density

Material	Mass/litre
Asphalt	1030 g/l
Butane	579
Crude Oil	850
Distillate	845
Petrol	739
Propane	507
Oil	944
Water	1000

Energy Output

Fuel	Energy Equivalent kCal
Bitumous Coal	5.8 -7.8 Million / Tonne
Wood	1.47 million / m3
Distillate	9350 / litre
Natural Gas	9350 / m3
Butane	6480 / litre
Propane	6030 / litre

Metric Pre Fixes

deka	10	deci	10^{-1}
hecto	10^{2}	centi	10^{-2}
kilo	10^{3}	milli	10^{-3}
mega	10^{6}	micro	10^{-6}
giga	10^{9}	nano	10^{-9}
tera	10^{12}	pico	10^{-12}
peta	10^{15}	femto	10^{-15}
exa	10^{18}	atto	10^{-18}

Appendix 5

Materials Analysis

An analysis of common building materials including data on toxic output, land degradation, energy consumption, transport requirements, manufacturing processes, durability and other relevant data.

Preliminary Materials Analysis and Data

The following appendix records and details findings of the EcoCost research into the procurement of a range of common building materials. The data is widely sourced from texts, regulatory authorities, industrial and academic research data, resource and production companies and industrial bodies. Sources may be found in the Annoted Bibliography.

The data listed here covers manufacturing energy requirements, pollutant output, land area usage, durability, density, a description of the material and usual production techniques.

Aluminium Alloys

	Aluminium	Alloys	fabricated	Recycled
Production Energy Requirements GJ/Tonne MJ / Kg	210.8	?	213.5	8.11
Production Plant Location	Bell Bay, Tas , (Gladstone Queensland ?)			
Raw material Location	Weippa, Queensland. (Domestic Supply)			
Land Area Degradation	48.01m^2 per tonne			
Density	2650 kg/m^3			

grams pollution /kg production

Particles	SO_x	CO	CO_2	HC's	Fl	BOD	COD	Cl	TSS	Dis Sol.
1.38	1.3	0.27	-	-	0.35	-	0.6	3.8	16.8	3.7

Also 2 tonnes of red mud per tonne of Al from the Bauxite

Durability

Aluminium Loss of Tensile Strength

Marine Environment	-	7% in 4 Years	100% in 60 Years (extrapolated)
Industrial Env.	-	14% in 30 Years	100% in 215 Years (extrapolated)
Rural Environment	-	2% in 20 Years	100% in 1000 Years (extrapolated)

Raw Materials - Extensive bulk mining in open cut mines for Bauxite, Crushings and overburden as waste products in some areas (though not Aust). Topsoil is replaced and regenerated after scouring, twenty year plus to recovery. Bauxite is transported to processing plants usually at railheads or port facilities where alumina is extracted. 4.8 t. of bauxite are required for the extraction of 1.95 t. of alumina which will give one tonne of smelted aluminium. In Australia the bulk of bauxite comes from the Weippa mines which process the ore at the port facility to Alumina and ship it to the two main aluminium plants at Bell Bay (Tas) and Gladstone (NSW). The metal produced in Tasmania has a lower EcoCost due to the regeneratable non-polluting power supplied by the Hydro Electricity system.

Transport - low grade ore railed or pipelined short distances to coastal processing and shipping plants. Refined alumina ores are shipped long distances to processing centres at which pure aluminium is manufactured. Aluminium ingots are shipped to localised manufacturing centres for reforming into sheet products, lightweight profiled sections and structural profiles.

Processing - Electrically powered electrolytic smelting to extract raw aluminium and for alloying. Extensive industrialisation and technology required. Large quantities of electrical energy used. Relatively clean, low pollution process though numerous pot gasses are given off in the smelting rooms and Fl, CO2 and some CFl's are waste products. The manufacture of one tonne of aluminium uses 1.95 tonnes of alumina, 0.5 tonnes of carbon anodes, 35kg of fluorine and 15000kWh of electricity.

Use - highly adaptable for casting and machining and latterly welding and cutting, highly malleable, very thin, strong sheeting available.

Treatment - due to its peculiar nature of forming an impenetrable oxide coating on exposed surfaces, aluminium, will not corrode in normal weathering circumstances and does not need external coating. It is often powder coated for aesthetic purposes.

Strong and very light - with advanced technology monocoque construction techniques for structures with minimum material usage. Recyclable readily with process currently in place, but with similar energy costs, less mining to new material production.

Longevity - not yet tested to full extremes owing to the latter emergence as a construction material. Though has been shown to give optimal performance in aircraft structural situations.

	Cement	Aggregates	Sand	Reinforcement
Production Energy Requirements	1.8 GJ/Tonne raw - 2.72 fabricated & Reinforced			
	7.85	0.64	2.0	71.0 GJ/Tonne

Production Plant Location	Goliath Cement, Railton. Northern Tas
Raw material Location	Local. (Domestic Supply)
Land Area Degradation	$0.72m^2$ per m^3(cement)
Density	300 - $2400kgm^3$

Toxic Output kg/ tonne production CEMENT

Particles	SO_x	CO	CO_2	K	NO_x	BOD	COD	pH	TSS	Dis Sol.
17	10.6	-	200	3.3	1.3	-	-	9.9	0.1	6.7

Durability

Concrete Loss of compressive Strength

Marine Environment	-	% in 4 Years	100% in Years (extrapolated)
Industrial Env.	-	% in 30 Years	100% in Years (extrapolated)
Rural Environment	-	% in 20 Years	100% in Years (extrapolated)

Raw Materials - About thirty raw materials in the following categories; lime, silica, alumina and ferrous compounds. Quarrying for limestones, alumina and calcites, silicates (sand Mining in some cases). Aggregates (bluemetal, quartzites, sand) are quarried widely with sources usually near the ready mixed concrete production plants

Reinforcing Steels are invariably required to give required strength to structural concrete. Sometimes fibres, either metal or glassfibre are employed in lightweight special purpose castings.

Transport - Cement plants are usually sited close to quarries as only smallish quarrying operations required and there is a high mass and volume of material to move. High transport costs are usually found from cement factory to concrete plant due to large masses involved. Concrete plants are usually close to major usage centres but large weights make for heavy transport requirements from the plant to the site.

Processing - dusty, polluting manufacturing but not usually high chemical toxicity or widespread outfalls. High energy process, usually electrically fired rotary kilns, conveyors, crushers and mixers.

Special pollution problems - A high level of CO_2 output from the process is a contributer to the present greenhouse crisis. High levels of fine dust produced, especially in accidental spills which may remain suspended in high winds.

Use - diverse usage potential for cement. On site aggregates, (gravels, sands, rammed earths) if available dramatically reduce transport requirements. Ready mix concretes have a high industrialisation component requiring large energy and transport costs.

Reinforcing steels need high industrialisation and transport.

Low tech generally in construction techniques, simple compression structures and spanning beams and floors. Some advanced structural systems are used. Lightweight concretes utilising fly ash as an aggregate have been widely used. Pre and post tensioning systems, and other engineered structures increases the strength and reduce the mass and volumes of materials required.

Treatment - Usually stable external surfaces though almost invariably used as a structural base for an aesthetic finish.

As a rule concretes are non re-usable or recyclable

Durability - Very long lifespan and are extremely durable except when poorly designed or exposed to strongly saline conditions.

Fabrics

	Canvas	Dacron	Teflon Coated F/Glass
Production Energy Requirements GJ/Tonne or MJ / Kg	?	890	?

Production Plant Location — Launceston, international

Raw material Location — Queensland, international

Land Area Degradation — ? m^2 per Tonne (negligible for oil derivatives)

Density — 1350 (PVC) - 1050 (Polystyrene) kgm^3

Durability

Varies widely according to type

Marine Environment - 100% in ? Years (extrapolated)
Industrial Env. - 100% in ? Years (extrapolated)
Rural Environment - 100% in ? Years (extrapolated)

kg/ tonne production

	CS_2	HS	HC	Oil	BOD	COD	pH	TSS	Dis Sol.
Rayon		27.5	3						
Nylon				3.5	7.5				
Dacron				3.5					

Raw materials - range of raw materials from regeneratable fibres to high tech plastic strands.

Transport - high component due to complexity and multiple staging of process, though material very light and non bulky.

Processing - high energy, high technology high industrialisation required. Natural raw material leads to low toxic outfall, high tech plastics create high toxin levels. There are three major steps in the process; Thread manufacture; Spinning; either molten, wet or dry, and; Weaving.

Special Pollution Problems - Mills usually driven with oil and coal fired machinery even when electrical power readily available.

Treatments - Fibres usually unstable and require some protection. High tech finishes such as Teflon, often used to protect fibre strands.

Use - High tech membrane constructions giving large areas of shelter with minimum material use.

Poor thermal properties, very flexible and strong, capable of exotic forms. Low volume low mass.

Non re-usable or recyclable due to fibre breakdown. Products such as Teflon Coated Fibreglass while breaking down as long fibres are essentially non-biodegradable and create a long term solid waste problem though the volumes are usually small.

Low durability, stability in full sun and high salinity areas a problem, as is attack by moulds and and fungi in shaded and continually moist areas.

Fibreglass

	Soda Lime	Recycled	Fibre making
Production Energy Requirements GJ/Tonne or MJ / Kg	22	6 - 13	15

Production Plant Location

Raw material Location — Local. (Domestic Supply)

Land Area Degradation — 3.33 m^2 per Tonne

Density — ? kgm^3

<u>Durability</u>

Varies widely according to species; see timber properties chart.

Marine Environment	-	100% in ? Years (extrapolated)
Industrial Env.	-	100% in ? Years (extrapolated)
Rural Environment	-	100% in ? Years (extrapolated)

Kg/tonne Textiles

Particles	SO_x	CO	CO_2	F's	NO_x	BOD	COD	Phenol	TSS	Dis Sol.
15.3	1.4	1.3	?	6.3	15.9	4.4	18.7	0.41	2.9	16

Kg/tonne Insulation Wool

Particles	SO_x	CO	CO_2	F's	NO_x	BOD	COD	Phenol	TSS	Dis Sol.
90.7	4.8	1.2	?	0.12	1.7	4.4	18.7	0.41	2.9	16

Raw materials - silica sand and additives for glass, Organic binders (?)

Transport - Extra transportation from glass manufacturer to F/Glass Producer. Bulky nature of fibreglass leads to underloaded transporters which slightly raises the transporting ecocosts/tonne km

Processing - Pelletised glass is molten and explosively forced through a sieved outlet resulting in bundles of fine fibres. An organic binder is sprayed over the hot fibres as they fall from the cell. In the case of Teflon coated F/Glass the organic binder is replaced with the durable, slippery, inorganic Teflon. High energy levels required for the melting of the glass.

Special Pollution Problems - Glass fibres are extremely fine and cause toxic like problems in ecosystems if released.

Durability - variable according to environment may become unstable and brittle in high uv light levels and high temperatures. The fibres can be very long lived, but the resins or binders used with it are often subject to breakdown and depolymerisation.

Glass

	Soda Lime	Recycled
Production Energy Requirements GJ/Tonne or MJ / Kg	22.03	6.62 to 13.1

Production Plant Location

Raw material Location — Local. (Domestic Supply)

Land Area Degradation — 3.33 m^2 per Tonne

Density — 2500 kgm^3

<u>Durability</u>

Varies widely according to species; see timber properties chart.

Marine Environment	-	100% in ? Years (extrapolated)
Industrial Env.	-	100% in ? Years (extrapolated)
Rural Environment	-	100% in ? Years (extrapolated)

kg/ tonne production Soda Lime Glass

Particles	SO_x	CO	CO_2	F	NO_x	BOD	COD	pH	TSS	Dis Sol.
1.0				2x F input						

Raw Materials - Silicates used for manufacture are sand mined from delicate ecologies with resulting high visual damage though due to the sparsely populated nature of the sand belt smaller species losses tend to occur. Limestone is quarried in various locations, dust being the major problem associated with mining, recent problems of interference with natural cave formations have been identified.
Transport - High transport costs from mining to plant to site due to localised nature of operations.

Process - Five basic types; Soda Lime (90%), Lead, Fused Silica, Borosilicate and 96% Silicate. Soda Lime Glass is the principal material used in structural works, it is produced in large, direct fired continuous melting furnaces (1480 ^oC) A moderate energy consumption is required

Use - Usually high tech fixing systems using highly industrialised products, aluminium, steel, silicons. Though traditional fixing systems using putties and timber battening have a much softer attitude.

Treatment - Virtually impervious to weathering through its life, this material is seldom treated except for aesthetic reasons during the construction process, ie mirror glass, tinted glass,

Glass is ecologically efficient for recycling and if care is taken can be re-used.

Durability - Glass is very durable though its life is often limited by its brittle nature and the rules of accidental damage. A "half life" longevity assessment would have to be made.

Manufactured timber products, plywoods, chipboards, composite boards, craftwood

	Plywood	Chipboard	Craftwood	Particle
Production Energy Requirements GJ/Tonne or MJ / Kg	61.25			

Production Plant Location	ANM Boyer, Launceston, APPM Burnie, Somerset (see Tasmanian Timber Promotion Board)
Raw material Location	Local. (Domestic Supply)
Land Area Degradation	$38m^2$ per Tonne (Clearfell)
Density	560 (light pines) - 1200 (dense gums) kgm^3

Durability

Varies widely according to species; see timber properties chart.

g/m^2 PLYWOOD

Particles	SO_x	CO	CO_2	HC's	NO_x	BOD	COD	Ozone	TSS	Dis Sol.
-	-	-	?	-	-	98.6	103.5	?	49.0	42.5

Raw material - Base resource renewable, but due to the industrialised nature of the operation usually relies on poor environmental management techniques in harvesting.

Transport - High transport costs from harvesting, to mill, to veneer mill, to ply plant, to vendor, to user.

Processing - Large industrialised process, high energy to break down raw material, chemicals widely employed for breakdown, and reconstitution.

Special Pollution Problems - Toxic chemicals especially formaldehydes released during life of boards - a large contributer to indoor air pollution problems. Highly toxic pollution outfall.

Treatment - almost all sheet products, with the exceptions of marine plywoods, unstable and will not withstand exposure to weather. Paints, Polyurethanes, and varnishes widely employed. Even treated sheets are not suitable for durable external construction.

Use - widely employed in construction for temporary forming, bracing and internal lining, low tech construction predominating. Some advanced high tech construction going on especially in large factory and warehouse style buildings.

Due to construction techniques of gluing, stapling and multi nailing, the sheets are often not re-usable, Possibly recyclable but not likely due to susceptibility to decay once surface treatment protection is lost. Simple and rapid construction, strong and predictable behaviour.

Durability - low to moderate, due to varying rate of breakdown of binding agents and surface treatments. Toxins released during breakdown.

Masonry

	Fired Clay	Conc Brick	Conc Block
Production Energy Requirements GJ/Tonne or MJ / Kg	1.8 - 5.44	1.7	1.42

Production Plant Location — Ulverstone, Launceston, Brighton, Hobart, Mornington, Railton , Latrobe

Raw material Location — Local. (Domestic Supply)

Land Area Degradation — 0.04 m^2 per m^3

Density — 1900 kgm^3 Clay Bricks - 3.6 kg/brick

<u>Durability</u>

Marine Environment	-	100% in ? Years (extrapolated)
Industrial Env.	-	100% in ? Years (extrapolated)
Rural Environment	-	100% in ? Years (extrapolated)

<u>Durability</u>

Concrete Loss of compressive Strength

Marine Environment	-	% in Years	100% in Years (extrapolated)
Industrial Env.	-	% in Years	100% in Years (extrapolated)
Rural Environment	-	% in Years	100% in Years (extrapolated)

kg/ tonne Bricks

Particles	SO_x	CO	CO_2	HC	NO_x	Flrde	COD	pH	TSS	Dis Sol.
17.5	3.6	0.95	?	0.3	0.45	0.5	-	9.9	0.1	6.7

Raw Materials - Heavy quarrying for raw materials, clays, gravels aggregates. Plants usually close to quarrying sites (though this is variable) and to usage centres. Cement is often used in non-clay bricks.

Transport - high cost of cement to plant, usually low cost due to proximity of other materials High cost of transport of bulk materials to site due to large masses.

Processing - High energy mixing, crushing conveying, extruding and kiln firing. Electrical energy most often used. Some wood fired kilns operating.

Use - simple low tech tech construction systems but highly flexible, traditional craft based techniques. Potential for use of on site materials to manufacture masonry elements, mud bricks and even fired kiln bricks.

Treatment - highly resistant to weathering and acceptable aesthetic leads to coating being rarely used.

Readily Re-usable, recyclable at cost, high transport penalties due to high weights.

Durability - Extremely durable and long lived, fired clay bricks may last millenia.

Plastics

	PVC moulded form	Polystyrene
Production Energy Requirements GJ/Tonne	184	
MJ / Kg		
Production Plant Location		
Raw material Location	Petroleum Byproducts	
Land Area Degradation	m^2 per Tonne (Capital Plant)	
Density	1350 (PVC) - 1050 (Polystyrene) kgm^3	

Durability

Varies widely according to type		
Marine Environment	-	100% in ? Years (extrapolated)
Industrial Env.	-	100% in ? Years (extrapolated)
Rural Environment	-	100% in ? Years (extrapolated)

kg/ tonne production

	Particulates	Gasses
Polyvinyl Chloride	17.5	8.5
Polypropylene	1.5	0.35
Others	2.5 - 5.0	

Raw Materials - most common raw materials are byproducts from the production of petroleum. Monomers, base compounds, usually either gaseous or liquid are supplied to the plastics industry by the refineries. Some new organically grown base monomers are being developed.

Transport - light nature makes for lower transport costs but usually due to complexity of plants long distances are involved.

Processing - Heavily industrialised high tech, high energy, high pollution manufacturing process with some high toxicity waste products. Monomers are reacted into polymers, dried and then treated and formed to achieve the desired product Some polymers are crushed to form powders, some are dissolved in solvents and others are suspended in latex solutions as they are removed from the kettle.

Special pollution Problems - Release of base compound monomers, often highly reactive during transport, storage and handling.

Long term toxic outfall problem.

Long term biodegradability problems with waste materials.

Short and medium term polymeric breakdown problems releasing toxins, esters, ethers, vinyls and ethylenes.

Treatments - Usually surface stable, weather resistant, with aesthetic finish built in, requiring no external finish.

Use - Not yet commonly used in building except as moisture proof barriers and DPCs High potential as structural and decorative elements.

Re-usability questionable, recyclable material with transport and energy penalties.

Very flexible and easily formed materials of moderate strength. High precision construction.

Durability - questionable, long term stability of polymers in doubt especially in exposed situations. May release toxins over time, particularly PVC's and polyethylenes.

Nylons are very durable but the fibres create ecological problems when released into the environment.

Pisse Terre (Rammed Earth)

	Pisse Terre	Soil Cement
Production Energy Requirements GJ/Tonne	0.2	
MJ / Kg		
Production Plant Location	On Site	as for cement
Raw material Location	Local. (Domestic Supply)	
Land Area Degradation	? m^2 per Tonne	
Density	2100 kgm^3 (Variable dependent on soil type)	

Durability

Varies widely according to exposure and soil type

Marine Environment	-	100% in ? Years (extrapolated)
Industrial Env.	-	100% in ? Years (extrapolated)
Rural Environment	-	100% in 5000 Years (extrapolated)

Kg/tonne Earth

Particles	SO_x	CO	CO_2	F's	NO_x	BOD	COD	Phenol	TSS	Dis Sol.
-	-	-	-	-	-	-	-	-	-	-

Raw materials - Usually available on site from the excavations for the structure. Very low ecocosting if no excavations outside of structure. Cement may employed as a binding agent in some soil types.

Transport - On site location of bulk materials leads to a very low transport component.

Production - Low energy, on site erection without treatment. Some mixing required. Suitable soil types required for successful construction

Use - Low tech, low energy construction systems. Compressive ramming sometimes performed mechanically. Reusable formwork units widely employed.

Treatment - Needs protection from the elements, wide eaves extensively used, whitewash and natural oil and manure based sealers may be employed.

Continually reusable, material unaltered in construction process.

Longevity - Highly resistant to rot, corrosion and solar weathering but needs protection from driven rain and moisture. Known to last millennia.

Stone

	Sandstone	Granite	Marble
Production Energy Requirements GJ/Tonne	0.5		
MJ / Kg			
Production Plant Location			
Raw material Location	Various See mines dept resource maps.		
Land Area Degradation	3.5 m^2 per Tonne		
Density kgm^3	1800 (limestone) -2200 (granite) - 3300 (dolerite) (Variable dependent on type)		

Durability

Varies according to exposure and type Sandstones may lose integrity after a couple of hundred years, marble is undamaged after millennia.

Kg/tonne Earth

Particles	SO_x	CO	CO_2	F's	NO_x	BOD	COD	Phenol	TSS	Dis Sol.
15.5	-	-	-	-	-	-	-	-	-	-

Raw Material - Small quarrying activities, highly labour intensive Noise may be an intermittent problem. Dust is the major ecocost involved.

Transport - heavy material leads to high transport costs. although transport distances are usually short for local stone.

Processing - Usually carried out at the quarry site High labour input low technology, low energy, almost no environmental degradation.

Use - Low tech using large quantities of stone in compression structures to high technology using thin sheets and veneers as protective facings.

Treatments - some stones are almost immune to weathering and some such as sandstone are only highly resistant. No full treatments are usually employed though softer stones are sometimes stabilised with poly urethane based varnishes.

Vast strength in compression but weak to all other loads.

Highly durable and easily reusable though not at present recycled though this is possible for reconstituted stones.